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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : G01S 5/02

A1

(11) International Publication Number: WO 99/23505

(43) International Publication Date: 14 May 1999 (14.05.99)

(21) International Application Number: PCT/KR98/00349

(22) International Filing Date: 3 November 1998 (03.11.98)

(30) Priority Data:
1997/57696 3 November 1997 (03.11.97) KR

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(81) Designated States: JP, US, European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

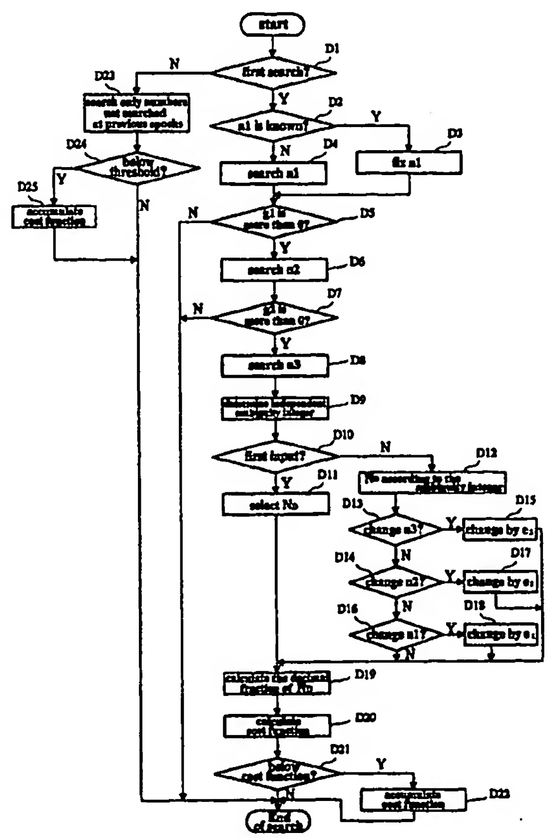
Published

With international search report.
Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.

(54) Title: METHOD FOR DETERMINING THE ATTITUDE OF A VEHICLE USING GPS SIGNALS

(57) Abstract

A GPS attitude determining method which is variously applicable to control of the orbit and attitude of satellites, entry of airplanes into the runway, operation of ships, arrangement upon flying, operation of vehicles, etc. When ambiguity integers have been already obtained, there is provided an attitude determination method using a global positioning system (GPS) of determining an attitude using the obtained ambiguity integers and carrier phase measurements. When ambiguity integers are not obtained, there is provided an attitude determination method using the GPS by which the attitude of a navigating body can be easily determined in real time by reducing the amount of calculation required to search for the ambiguity integers using an ambiguity integer search method using a constraint equation. Accordingly, the amount of calculation necessary for searching for the ambiguity integers can be significantly reduced, so that the attitude of a navigating body can be determined in real time. Also, the ambiguity integers are consecutively determined even in the case of insufficient visible satellites and upon blocking of the satellite signal which may occur in real operating circumstances, thus determining the attitude of a navigating body. Furthermore, an accurate attitude of about several mdeg is provided by using the carrier phase measurements.



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METHOD FOR DETERMINING THE ATTITUDE OF A VEHICLE USING GPS SIGNALS

TECHNICAL FIELD

The present invention relates to an attitude determination method using a global positioning system (GPS), and more particularly, to an attitude determining method using the GPS, wherein an attitude is determined by using integer ambiguities when the integer ambiguities are obtained, and carrier phase measured values. Also, the present invention relates to an attitude determination method using the GPS, by which the attitude of a navigating body is easily determined in real time by reducing the amount of calculation which is required to search for integer ambiguities using a constraint equation.

BACKGROUND ART

The GPS for obtaining a position using satellites has been widely used because of its convinence and accuracy. The GPS is usually used in applications for obtaining an absolute position on the earth using a coarse/acquisition (C/A) or precision (P) code by connecting an antenna to one receiver. In the case of the C/A code, the GPS has an error of about 100m (2dRMS(Root Mean Square)) under the influence of selective availability by the Pentagon (Department of Defense in U.S.A.). A differential GPS (DGPS) has also been widely used to overcome this error. Here, the DGPS can obtain accuracy of several m or less by offsetting SA, delay of the ionosphere, delay of the troposphere, and an error of a satellite orbit by estimating an error included in a measured value of each satellite in a known place (reference station) and transmitting this presumed error to other neighboring receivers.

In a geodetic field as a representitive application field using GPS, a

carrier phase signal rather than a code signal is used to obtain a more accurate position. That is, in the case of the C/A code, a chip (an interval at which 0 or 1 is transmitted by a binary pulse code: 1μs) is 300m long, and it can be considered that the chip has a resolution of about 3m if it is measured by a resolution of 1%. However, the wavelength of the carrier phase is 19cm, and the carrier phase has a resolution of 1.9mm if it is measured by a resolution of 1%. This carrier phase can allow to obtain an excellently accurate position. However, a measured value of the carrier phase includes an initial integer ambiguity, so that the carrier phase cannot be used until the initial integer ambiguity is obtained. The initial integer ambiguity is included when an initial satellite signal is received, and once the value is obtained, it is not necessary to reobtain the initial integer ambiguity while the satellite signal is continuously received. That is, the intial integer ambiguity has a constant value with respect to the time, but can be treated as a random constant which varies whenever the satellite signal is received for the first time. Accordingly, the geodetic field not frequently requring to obtain a position in real time has researched a method using the carrier phase long since. A geodetic survey uses a relative positioning method for obtaining a relative position with respect to a reference position. According to this method, when a base station whose location is already known is close to a receiver whose location is to be calculated, a differential method is used to determine the relative position, thereby effectively compensating for common errors.

The obtained relative position becomes a vector for connecting two places, and is defined as a baseline vector. Assuming that the baseline vector is fixed to an aviating body (e.g., ships, airplains, or vehicles), the attitude of the aviating body can be determined by measuring the change in the baseline vector. However, before the carrier phase is used in the aviating body, an interger

ambiguity included in the carrier case must be determined in real time.

A conventional method for determing the position and attitude of an aviating body using GPS will now be described.

First, the position of the satellite and the distance between the satellite and the receiver must be measured to obtain the position using a code signal of the GPS. For this, the satellite transmits to a user a signal (code signal and aviation signal) capable of measuring the position and distance of the satellite, and then the receiver calculates the position of the satellite using the aviation signal. Also, the distance between the satellite and the receiver is obtained by measuring the time while a radio wave is finally transmitted using the code signal. For this, the time between the satellite and the receiver must be accurately synchronized with each other. However, a clock in the receiver usually uses an inaccurate cheap oscillator, so that the measured distance includes a bias corresponding to a receiver clock error. Accordingly, the distance measured by the receiver is called a pseudorange, and the receiver clock error besides the position of the receiver is added as a new unknown quantity to be calculated. Since the position and time are simultaneously obtained by using a measured pseudorange value with respect to four or more satellites, the GPS can be applied not only to an application requiring the aviation, the geodetic survey, and the position for attitude measurement but also to communications requring a correct time.

A measured pseudorange value calculated by a code signal from an i-th satellite compensates for the satellite clock error, the ionosphere delay, and the troposphere delay using an aviation signal from the corresponding satellite, and can be expressed by Equation 1:

【equation 1】

$$\Psi^i = r^i + cB + \nu^i$$

wherein B indicates a receiver clock bias, c is the velocity of light, and ν^i indicates a measured noise including SA.

Also, the distance r_i between the satellite and the receiver is expressed by $r_i=\sqrt{(X_i-x)^2+(Y_i-y)^2+(Z_i-z)^2}$ using the position $[X_i\ Y_i\ Z_i]^T$ of the satellite and the position $p=[x\ y\ z]^T$ of the receiver to be obtained.

Equation 1 is linearized and thus can be transformed into Eqiation 2:

【equation 2】

$$\delta\Psi^i = h_i^T\delta p + cB + \nu^i = [\ h_i^T\ \ 1] \begin{bmatrix} \delta p \\ cB \end{bmatrix} + \nu^i$$

Here, an initial line vector, expressed by $h_i=\left[\frac{\partial \Psi_i}{\partial p}\right]_{p0}=[\frac{x_0-X}{[r_i]_0}\ \frac{y_0-Y}{[r_i]_0}\ \frac{z_0-Z}{[r_i]_0}]^T$, is calculated from a linearized reference point P_0, and δp is equal to $[\ \delta x\ \ \delta y\ \ \delta z]^T$.

A measurement expression with respect to m (four or more) satellites is formed to the following Equation 3, and when the covariance of a measuring error is expressed by the following Equation 4, the position of the receiver and the receiver clock error can be obtained by the following Equation 5. From the below Equation, we have the results that a final position to be calculated is $p_0+\delta\hat{u}$, and the receiver clock error is $\delta\hat{u}$.

【equation 3】

$$\delta\Psi = \begin{bmatrix} h_1^T & 1 \\ \cdot & \cdot \\ \cdot & \cdot \\ h_m^T & 1 \end{bmatrix} \begin{bmatrix} \delta p \\ cB \end{bmatrix} + \nu \equiv A\delta u + \nu$$

【equation 4】

$$Q = diag(\sigma^2_{\nu 1}, \sigma^2_{\nu 2}, \cdots, \sigma^2_{\nu m})$$

【equation 5】

$$\delta \hat{u} = (A^T Q^{-1} A)^{-1} A^T Q^{-1} \delta \Psi$$

A method of calculating a relative position using a double-differenced code signal will now be described, which is applied to the case of using the carrier phase having a determined integer ambiguity. A measured double-differenced code value is expressed by the following Equation 6, where common errors (e.g., the SA, the delays of troposphere and ionosphere, the receiver clock error, etc.) between a base statition receiver A and a user receiver B shown in FIG. 1 are compensated for:

【equation 6】

$$\Psi^{ij}_{AB} \equiv (\Psi^j_B - \Psi^i_B) - (\Psi^j_A - \Psi^i_A) = r^{ij}_{AB} + \nu^{ij}_{AB}$$

Equation 6 is linearized at the position $A = [\ x_A \ \ y_A \ \ z_A]^T$ of the base station and an arbitrary reference point $B_0 = [\ x_{B0} \ \ y_{B0} \ \ z_{B0}]^T$, thereby obtaining the following Equation 7:

【equation 7】

$$\Psi^{ij}_{AB} = \Psi^j_{B0} - \Psi^i_{B0} - \Psi^j_A + \Psi^i_A - \frac{X_j - x_{B0}}{\Psi^j_{B0}} \delta x_{B0} - \frac{Y_j - y_{B0}}{\Psi^j_{B0}} \delta y_{B0} - \frac{Z_j - z_{B0}}{\Psi^j_{B0}} \delta z_{B0}$$

$$+ \frac{X_i - x_{B0}}{\Psi^i_{B0}} \delta x_{B0} - \frac{Y_i - y_{B0}}{\Psi^i_{B0}} \delta y_{B0} - \frac{Z_i - z_{B0}}{\Psi^i_{B0}} \delta z_{B0}$$

$$+ \frac{X_i - x_{B0}}{\Psi^i_{B0}} \delta x_{B0} - \frac{Y_i - y_{B0}}{\Psi^i_{B0}} \delta y_{B0} - \frac{Z_i - z_{B0}}{\Psi^i_{B0}} \delta z_{B0}$$

$$+\frac{X_j - x_A}{\Psi^j_A}\delta x_A + \frac{Y_j - y_A}{\Psi^j_A}\delta y_A + \frac{Z_j - z_A}{\Psi^j_A}\delta z_A$$

$$-\frac{X_i - x_A}{\Psi^i_A}\delta x_A - \frac{Y_i - y_A}{\Psi^i_A}\delta y_A - \frac{Z_i - z_A}{\Psi^i_A}\delta z_A$$

If the position of the base station is correctly recognized, we can acquire the result of $\delta x_A = \delta y_A = \delta z_A = 0$ from Equation 7. thus, Equation 7 can be simplified to the following Equation 8:

【equation 8】

$$\rho^{ij}_{AB} = h^{ij\,T}_{B0} \cdot \begin{bmatrix} \delta x_{B0} \\ \delta y_{B0} \\ \delta z_{B0} \end{bmatrix} + \nu^{ij}_{AB} \equiv h^{ij\,T}_{B0}\,\delta x + \nu^{ij}_{AB}$$

Here, when h^{ij}_{B0} is defined as in Equation 9, the following Equation 8 can be rearranged to Equation 10:

【equation 9】

$$\rho^{ij}_{AB} \equiv \Psi^{ij}_{AB} - (\Psi^j_{B0} - \Psi^i_{B0} - \Psi^j_A + \Psi^i_A) = \Psi^{ij}_{AB} - \Psi^{ij}_{AB0}$$

【equation 10】

$$h^{ij}_{B0} \equiv h^j_{B0} - h^i_{B0} =$$

$$\left[-\frac{X_j - x_{B0}}{\Psi^j_{B0}} + \frac{X_i - x_{B0}}{\Psi^i_{B0}} \quad -\frac{Y_j - y_{B0}}{\Psi^j_{B0}} + \frac{Y_i - x_{B0}}{\Psi^i_{B0}} \quad -\frac{Z_j - z_{B0}}{\Psi^j_{B0}} + \frac{Z_i - z_{B0}}{\Psi^i_{B0}} \right]^T$$

When measured values with respect to m satellites are arranged as in the following Euqation 11, a double-difference operation $(\cdot)^{ij}_{AB}$ can be expressed by the following Equation 12:

【equation 11】

$$\Psi = [\ \Psi_A^1,\ \Psi_B^1,\ \Psi_A^2,\ \Psi_B^2,\ \cdots,\ \Psi_A^m,\ \Psi_B^m]^T$$

【equation 12】

$$\begin{bmatrix} \Psi_{AB}^{12} \\ \cdot \\ \cdot \\ \Psi_{AB}^{(m-1)m} \end{bmatrix} = \begin{bmatrix} 1 & -1 & -1 & 1 & 0 & 0 & 0 & 0 & \cdots & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & -1 & -1 & 1 & 0 & 0 & \cdots & 0 & 0 & 0 & 0 \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdots & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdots & \cdot & \cdot & \cdot & \cdot \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & 1 & -1 & -1 & 1 \end{bmatrix} \begin{bmatrix} \Psi_A^1 \\ \Psi_B^1 \\ \Psi_A^2 \\ \Psi_B^2 \\ \cdot \\ \cdot \\ \Psi_A^m \\ \Psi_B^m \end{bmatrix}$$

Also, the double-difference operation can be defined by a DD operator of the following Equation 13:

【equation 13】

$$DD = \begin{bmatrix} 1 & -1 & -1 & 1 & 0 & 0 & 0 & 0 & \cdots & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & -1 & -1 & 1 & 0 & 0 & \cdots & 0 & 0 & 0 & 0 \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdots & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdots & \cdot & \cdot & \cdot & \cdot \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & 1 & -1 & -1 & 1 \end{bmatrix}$$

Equation 10 is broadened with respect to the m satellites using the DD operator of Equation 13, so that it can be reformed to the following Equation 14:

【equation 14】

$$\rho \equiv DD \cdot \Psi = [\ h_{B0}^{12}\ \ h_{B0}^{23}\ \ \cdots\ \ h_{B0}^{(m-1)m}]^T \cdot \begin{bmatrix} \delta x_{B0} \\ \delta y_{B0} \\ \delta z_{B0} \end{bmatrix} + DD \cdot \upsilon \equiv H\delta x + \nu$$

Here, a measured error is defined by the same method as Equation 11, as $\nu = [\nu_A^1, \nu_B^1, \nu_A^2, \nu_B^2, \cdots, \nu_A^m, \nu_B^m]^T$.

When an initial line vector is defined by the following Equation 15, a

matrix H can be expressed by the following Equation 16 using an operator C of the following Equation 17:

【equation 15】

$$\Xi = [\ h_B^1, h_B^2, \cdots, h_B^m]^T$$

【equation 16】

$$H = C \cdot \Xi$$

【equation 17】

$$C = \begin{bmatrix} -1 & 1 & 0 & \cdots & 0 & 0 \\ 0 & -1 & 1 & \cdots & 0 & 0 \\ \cdot & \cdot & \cdot & \cdots & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdots & \cdot & \cdot \\ 0 & 0 & 0 & \cdots & -1 & 1 \end{bmatrix}$$

The relative position of the receivr B can be obtained using Equation 14 and the measured values obtained by the two receivers A and B. However, while using the DD operator, a measured noise between receiver channels has a correlation. Accordingly, this must be considered to obtain the solution of the relative position. That is, a covariance Q_Ψ of a non-double-differenced measured value (υ) is expressed by the following Equation 18 through double difference:

【equation 18】

$$cov(\nu) = DD \cdot cov(\upsilon) \cdot\ DD^T = DD \cdot Q_\Psi \cdot\ DD^T \equiv Q_{D\Psi}$$

Also, the solution by the weighted least square considering the Equation 18 is the following Equation 19:

【equation 19】

$$\delta\hat{x} = (H^T Q_{D\Psi}^{-1} H)^{-1} H^T Q_{D\Psi}^{-1} \cdot \rho$$

In the same way as the code, the following Equation 20 can be obtained with respect to a double-differenced carrier phase:

【equation 20】

$$l_{AB}^{ij}(t) = h_{B0}^{ij}(t)^T \delta x(t) + \lambda N_{AB}^{ij} + w_{AB}^{ij}(t)$$

wherein λ is a wavelength (about 19cm) of an L1 carrier phase signal, N_{AB}^{ij} is a double-differenced integer ambiguity, and $w_{AB}^{ij}(t)$ is a double-differenced receiver error.

Equation 20 will be used in an ambiguity resolution with constraint equation (ARCE) to be described later.

Equation 20 includes three positions and four unknown quantities comprised of an integer ambiguity. If the Equation 20 knows the integer ambiguity, it is a measurement expression including only a very small receiver measured noise. Thus, an accurate position can be measured by using the Equation 20.

(m-1) double-differenced measurment expressions can be obtained with respect to m satellites and represented at an epoch t as the following Equation 21:

【equation 21】

$$l(t) = H(t)\,\delta x(t) + \lambda N + w(t), \qquad w \sim N(0, Q_{D\phi})$$

wherein l indicates $[\, l_{AB}^{12} \cdots l_{AB}^{(m-1)m}]^T$, w is $[\, w_{AB}^{12} \cdots w_{AB}^{(m-1)m}]^T$, and N is $[\, N_{AB}^{12} \cdots N_{AB}^{(m-1)m}]^T$. Here, $N(0,Q_{D\phi})$ denotes that a double-differenced receiving error has a normal distribution, and $Q_{D\phi}$ indictes the dispersion of a receiving error transformed by the DD operator in Equation 13.

When the double-differenced carrier phase is used, the common errors are completely compensated within several ㎞, so that it is possible to measure an accurate position which can be represented even in units of ㎜. That is, if using the carrier phase, the position of an antenna to be obtained from a reference point can be calculated with accuracy of several ㎜.

Equation 21 includes $3+(m-1)$ unknowns. Here, when $(m-1)$ integer ambiguities are determined, an accurate position can be obtained using four or more satellites, which provokes many researches for obtaining the integer ambiguities.

However, as to determination of the ambiguity integers, unknowns to be obtained with respect to the measured value of one epoch are more than the measured values, and has a constraint of integers, so that it is impossible to analytically find the ambiguity integers. Also, since convexity is not ensured in an integer region, the solution cannot be obtained even by non-linear programming. Accordingly, a method of searching regions where ambiguity integers will exist is usually used. Many researches into the determination of the ambiguity integers have been made in the geopedic survey as a representivive applicication field requiring accurate position measurement. Recently, many researches into the attitude measurement field are also in progress. The main object of the geopedic survey is to obtain an accurate position. In the beginning, the geopedic survey usually used an averaging method, and now usually has used a post processing method. Also, the geioeduc survey aims at reducing the amount of calculation. Meanwhile, the attitude measurement requires real time processing, thereby aiming at obtaining ambiguity integers with a measured value. In the attitude determination in contrast to the geopedic survey, the distance between antennas is known, so that it can be used in determining the ambiguity integers. Also, if using extra antennas, the determined ambiguity integers can be

also easily inspected. However, even in the attitude determination case, it is difficult to determine the ambiguity integers with the measured value of one epoch under the influence of the measured noise, thus determining the ambiguity integers using measured values at several epoches. Here, the determination of the ambiguity integers varies according to whether a multi-epoch approch or an epoch-by-epoch approach is used. That is, in the multi-epoch approach, it is general that the position and ambiguity integers are determined by using only the carrier phase. However, in the epoch-by-epoch approach, the solution is obtained by using both the code and the carrier phase. The two approaches have similarities and differences therebetween, but the latter capable of determining ambiguity integers with a measured value is usually used in the aviation and the attitude measurement.

The ambiguity integers are determined by searching under integer conditions. OTF (on-the-fly) techniques based on the geopedic survey, using an integer weighted least square method capable of determined the ambiguity integers while moving, use only the carrier phase and require an estimated value for each ambiguity integer in a real number area. Thus, measured values at several epoches must be gathered to be used in the OFT techniques. Accordingly, when the measured values are collected in a short time, a search range for the ambiguity integers is widened to increase the amount of calculation necessry for searching. On the other hand, when the time for collecting becomes longer, the search range narrows, but the amount of calculation at each search point increases. Also, application in real time is difficult without consideration for a change in satellite during searching the ambiguity integers. In particular, when a satellite signal is blocked even after the ambiguity integers are determined, all the ambiguity integers must be obtained again.

Meanwhile, a conventional least square ambiguity search techinigue

(LSAST), proposed to apply the attitude determination, uses both the code signal and the carrier phase signal, and is characterised in that a satellite is divided into primary and secondary satellites. Here, the position of the main satellite can be obtained by calculating the ambiguity integers with respect to the main satellite, and then the ambiguity integers with respect to the secondary satellite can be obtained. That is, this indicates a method of determining the ambiguity integers using surplus satellite information. Here, a position measured by only the main satellite is corrected into information on the secondary satellite by using a sequential least squares method. The process for determining the ambiguity integers using LSAST will be summarized as follows.

First, a real number solution and a search range are determined by a double-differenced code, and a satellite is then classified into four main satellites and the residual secondary satellites. Here, a double-differenced carrier phase expression is also divided according to the type of satellite.

Second, other ambiguity integers to be searched are determined. Here, only the ambiguity integers with respect to the main satellites are searched, and the ambiguity integers of the secondary satellites are obtained according to a resultant expression formed by the above search.

Third, the position is compensated for, and an criterion function is calculated, by the sequential least squares method using the measured values of the secondary satellites.

Fourth, if the calculated criterion function is greater than a threshold, the corresponding other ambiguity integers are excluded from the object of search. In this way, unnecessary searches are deleted, to reduce the amount of calculation.

In such a LSAST, the ambiguity integers theoretically can be determined using one measured value, and only the ambiguity integers with respect to the

main satellite can be searched. Thus, the LSAST is the most frequently used in the attitude measurement. However, the basis for selection of the main satellites is ambiguous, and there is no concrete basises for determining a critical value, so that true ambiguity integers are highly likely to be removed during search. Also, the position for each ambiguity integer candidate must be calculated, thereby increasing the amount of calculation. furthermore, a change in satellite during searching for the ambiguity integers is not considered, and all ambiguity integers must be again obtained when a satellite signal is blocked even after the ambiguity integers are determined.

DISCLOSURE OF THE INVENTION

A baseline vector, that is as accurate as can be calculated in units of mm, can be obtained using a carrier phase measured value of a global positioning system (GPS). The attitude of an aviating body can be obtained from the movement of the baseline vector. However, an initial ambiguity integer included in the measured value must be obtained to use the GPS carrier phase measured value. Once the initial ambiguity integer is determined, a satellite signal is contineously tracked, and the determined value can be contineously used as long as no cycle slip occurs. Determination of the ambiguity integers is made by searching, and has been used in a geopedic survey field not requiring real time, since real time accomplishment is difficult because of an extensive search range and the massive amount of calculation. However, there is more necessity to use the GPS carrier phase measured value also in a navigation field to meet the requirement of an accurate naviation for vehicles travelling down-town areas.

In the present invention, a consecutive attitude of an navigating body is obtained in real time from the GPS carrier phase measured value, by performing the following methods.

First, a method of determining ambiguity integers with one measured value is provided. This method is performed by reducing the number of ambiguity integer candidates to be searched and the amount of calculation to be executed for each candidate.

Second, once the ambiguity integer is determined, the value is contineously used before a satellite signal is blocked or the cycle slip occurs, thereby obtaining a reduction in the amount of calculation. This method can be accomplished by detecting a change in satellites and generation of the cycle slip with respect to the measured value of each epoch and rearranging the order of satellites and ambiguity integers.

Third, when the ambiguity integer is obtained and four satellites are visible, the attitude of a navigating body is determined using the measured value with respect to a carrier phase.

Fourth, even if 3 satellites are visible, the attitude of a navigating body is obtained using the conditions that the length of a baseline is known.

Fifth, if two satellites are visible, when ambiguity integer values with respect to the corresponding satellites are stored, and the number of visible satellites increases, the ambiguity integers are effectively determined using the stored values.

Sixth, when determination of ambiguity integers fails in the first method, the ambiguity integers will be determined by additionally using the measured value of a next epoch. Here, the object to be searched corresponds to only a candidate which underwent a critical value inspection to be described later, thus reducing the amount of calculation. The attitude at this epoch can be consecutively output by informing a user of an attitude obtained by using a code signal and its circumstances.

An accurate attitude can be consecutively provided to a user in real time by solving the technical problem using the above-described methods.

Accordngly, it is a first object of the present invention to provide an attitude determination method using GPS, by which the attitude of a navigating body is obtained using ambiguity integers and carrier phase measured values if the ambiguity integers are already obtained.

It is a second object of the present ivnention to provide an attitude determination method using GPS, by which the attitude of a navigating body is obtained even when the number of satellites is reduced to 3 in the case that ambiguity integers are determined.

It is a third object of the present ivnention to provide an attitude

determination method using GPS, by which the attitude of a navigating body is obtained by appropriately rearranging the sequence of satellites according to a change in the number of visible satellites and determining ambiguity integers.

It is a fourth object of the present ivnention to provide an attitude determination method using GPS, by which the attitude of a navigating body is obtained quickly even when ambiguity integers are not obtained, by obtaining the ambiguity integers in real time by reducing the search range for the ambiguity integers and minimizing the amount of calculation for each ambiguity integer candidate within the search range.

It is a fifth object of the present ivnention to provide an attitude determination method using GPS, by which the attitude of a navigating body is obtained quickly by an ambiguity integer search method by which the amount of calculation can be reduced by narrowing the performing search range using the measured value of a next epoch, when ratio inspection performed during searching for the ambiguity integers fails under the influence of a measured noise, etc.

It is a sixth object of the present ivnention to provide an attitude determination method using GPS, by which the attitude of a navigating body is obtained by maintaining ambiguity integers robustly determined even when a satellite signal is blocked in real operation circumstances.

In order to describe the configuration of the present ivnention having the first object, necessary coordinate systems will be first defined as follows.

In the GPS, a WGS-84 coordinate system is used as a reference coordinate system, and is called an earth centered fixed (ECCF) coordinate system. However, an initial baseline vector is expressed in a body frame, and an attitude is defined from the body frame and a navigation frame. Each of the above body frame and the navigation frame will now be described.

1. WSG-84 frame

The WSG-84 frame rotates with the earth with the center of the earth as the origin, and is defined as follows.

Here, the origin is a gravity center of the earth

Z^W is the direction of a conventional terrestrial pole (CTP) defined in

1984 by a bureu international de l'heure (BIH), which becomes the rotational axis of the WSG-84 frame.

Y^W is defined as the intersection point between an equatorial plane and a reference meridian which are defined from the CTP, and the reference meridian passes through Greenwich Observatory.

X^W is defined as a right-handed system (RHS) by Z^W and Y^W, and exists on the equatorial plane.

2. navigation frame

This is a coordinate for navigation. Here, an east-north-up (ENU) frame will be described instead of the nagivation frame.

The origin is the position of a reference antenna when one of several antennas is the reference antenna, and is consistent with the origin of the body frame.

X^n is the est direction.

Y^n is the north direction.

Z^n is perpendicular to the X^n-Y^n plane, and is in the opposite direction to the center of earth.

FIG. 2 shows the relationship between the WGS-94 frame and the navigation frame. Here, P denotes the origin of the navigation frame, and lg, lt and h denote degree of slope, latitude, and altitude, respectively. The origin (P) is set to be the position of the reference antenna, and obtained by an absolute positioning method using a code. Since a relative positioning method is used in attitude measurement, accuracy of the position of the origin does not matter. That is, an influence of an error of the origin on the accuracy of the baseline vector obtained by the relative positioning method can be ignored in position determination. The coversion between the WGS-84 frame and the navigation frame can be expressed by the following Equation 22:

【equation 22】

$$r^n = C_e^n r^e$$

wherein γ^{n}, being $[x^{n}\ y^{n}\ z^{n}]^{T}$, is a vector in the avigation frame, γ^{e}, being $[\Delta x\ \Delta y\ \Delta z]^{T}$, is a vector (obtained baseline vector) in the WGS-84 frame wherein P is the origin, and C_{e}^{n}, being $\begin{bmatrix} -\sin lg & \cos lg & 0 \\ -\sin lt \cos lg & -\sin lt \sin lg & \cos lt \\ \cos lt \cos lg & \cos lt \sin lg & \sin lt \end{bmatrix}$, is a conversion matrix.

3. body frame

Since the body frame defined by a navigating body is consistent with a frame where an antenna is installed, the antenna frame and the body frame must be discriminated in the strict sense of the word. However, on the assumption that the navigating body is rigid, a misalignment angle between the antenna frame and the body frame is constant. this can be considered when obtaining an attitude. Thus, assuming that the body frame is consistent with the antenna frame, it is defined as follows.

Y^b is the foward direction of the body

X^b is the right direction of the body

Z^b is perpendicular to the X^b-Y^b plane and upward

The origin, as the intersection point of X^b, Y^b, and Z^b, is consistent with the position of a reference antenna.

The attitude of the navigating body is defined as the angle between the navigation frame and the body frame. FIG. 3 shows the body frame and the attitude angle. In FIG. 3, arrows denote the positive directions of a roll (Φ), a pitch (Θ), and a yaw (Ψ). Here, the yaw is an angle between the Y^b axis and the north and positive counterwise. The roll indicates the rotation of the body around the Y^b axis, and is positive on the right. the pitch indicates the rotation around the X^b axis, and the upward direction of the forehead of the navigating body is defined as positive.

[example of two-dimensional attitude determination]

If two antennas are attached to a navigating body, a baseline vector between the two antennas can be accurately obtained. The attitude determination using the GPS is accomplished by attaching several antennas to the body as described above and measuring the baseline vector between antennas using a

carrier phase. Hereinafter, the attitude determination using the baseline vector will be described.

First, an attitude determining method through two antennas A and B installed in the body frame as shown in FIG. 3 will be described by taking an exemple. Here, an antenna A is set to be a reference antenna and defined by the origin of the body frame. the direction perpendicular to the plane on which the antennas A and B exist is indicated by an axis (z), and the direction of the antenna B is indicated by an axis (x). FIG. 3 shows an axis (y) indicating the direction perpendicular to the axis (x). When the baseline length between the antennas A and B is set as L_b as shown in FIG. 3, the antenna B can be expressed by (0, L_b, 0) in the body frame. Here, the baseline vector in the WGS-84 frame obtained using the GPS carrier phase is converted into the state of the body frame, and can be expressed by the following Equation 23:

【equation 23】

$$r_B = (x_B, y_B, z_B)$$

Accordingly, the yaw and the pitch can be obtained using the fact that Υ_B is equal to (x_B,y_B,z_B), by the following Equation 24:

【equation 24】

$$\psi = -\tan^{-1}\left(\frac{x_B}{y_B}\right)$$

$$\theta = \tan^{-1}\left(\frac{z_B}{\sqrt{x_B^2 + y_B^2}}\right)$$

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates a method of obtaining a relative position using a

not yet determined after power is applied, the procedure goes to the step of obtaining the ambiguity integers. If the ambiguity integers has been predetermined, the procedures goes to the step of obtaining an attitude using a carrier phase.

The step S5 is of detecting a change in the satellites. Here, a satellite commonly measured by the reference antenna and the other antennas is extracted, and the extracted satellite is compared with a satellite used at a just previous epoch. If no change in the satellites is detected, the pre-obtained ambiguity integers can be used without change, and thus the procedure goes to the step of obtaining the attitude. On the other hand, if a change in the satellites is detected, the procedure goes to the step of verifying the change.

The step S6 is of determining the occurance or non-occurance of a cycle slip, i.e., the case that the measured carrier phase is discontinuous due to blocking of the satellite signal. if the cycle slip occurs, the ambiguity integers in the carrier phase must be again determined, that is, the procedure moves to ⓐ in FIG. 4C. The cycle clip can be detected by calculating an object function value using an obtained independent ambiguity integer and comparing the result to an obtained critical value. The object function obtained by the determined ambiguity integer is expressed by the following Equation 25:

【equation 25】

$$\Omega_E(t) = \lambda^2 \delta N_D^T [E_D(t) Q_E^{-1}(t) E_D^T(t)] \delta N_D$$

wherein δN_D is determined by a dependent ambiguity integer calculated using the obtained independent ambiguity integer N_I. This process will be described in more detail in the process for searching for the independent ambiguity integer to be described later. Meanwhile, α in Equation 26 is a constant which is determined by a user, and ranges between 0 and 0.5. Generally, it is preferable that α is determined according to the performance and circumferences of the receiver and ranges from 0.05 to 0.1. The expression for determining the occurrence or non-occurrence of the cycle slip using the object

double-differenced code signal;

FIG. 2 illustrates a relationship between a WGS-84 frame and a navigation frame;

FIG. 3 illustrates a body frame and a denotion of an attitude angle;

FIG. 4A through 4C are flowcharts for illustrating embodiments of the present ivnention; and

FIG. 5 is a flowchart for illustrating an integer ambiguity search method according to the present invention.

BEST MODE FOR CARRYING OUT THE INVENTION

Preferred embodiments of the present ivnention will now be described referring to the attached drawings. Also, the claimed scope of the present embodiments is not be limited, and these embodiments are just examples.

FIGS. 4A through 4D are flowcharts for illustrating the embodiments of the present ivnention.

[attitude determination method using predetermined ambiguity integers]

Referring to FIG. 4A, the step S1 is of initializing information necessary for obtaining an attitude and ambiguity integers, and in this step, the distance between two antennas, a coefficient value for coordinate conversion, etc., are defined.

The step S2 is of receiving an epoch data item. Here, a reference antenna and the other antennas must acquire measured values at the same time. For this, a receiver must accurately synchronize the times of channels each processing a signal provided by the antenna with each other. Data transmitted to a microcomputer unit includes personal numbers (PRN) of satellites by channels, the positions of the satellites, a pseudorange measured by a code signal, and a pseudorange measured by a carrier phase signal.

The step S3 is of obtaining the position of the reference antenna using the measured value of a code.

The step S4 is of determining whether ambiguity integers are predetermined. in this step, if this is the first stage or the ambiguity integers are

function and the critical value is shown as the following Equation 27:

【equation 26】

$$x(t) = a^2\lambda^2\nu^T[E_D(t)Q_E^{-1}(t)E_D^T(t)]\nu$$

【equation 27】

$$\Omega_E(t) \leq x(t)$$

The step S7 is of calculating the positions of the residual antennas with respect to the reference antenna from the carrier phase measured value having determined ambiguity integers and obtaining an attitude using the obtained residual antenna positions.

[method of obtaining an attitude using three satellites]

FIG. 4B is a flowchart for illustrating a method of obtaining an attitude using 3 satellites.

The steps S1 and S2 in FIG. 4B are the same as those in FIG. 4A, so will not be described again. the step S2′ is of detecting the number of satellites. Here, if the number (m) of satellites is 4 or more, the procedure goes to the step S3 shown in FIG. 4A. If the number of satellites is 3, the procedure goes to the step S3′ of obtaining the position of the reference antenna using the 3 satellites.

The step S3′ can be performed by two methods which are a receiver clock fixing method and an altitude fixing method.

The receiver clock fixing method can be described as follows.

On the assumption that a clock error of a receiver does not sharply change by virtue of the technical development of receivers, when 3 satellites are installed, the position of the reference antenna is obtained using a value cB_f obtained when the number of visible satellites is 4 or more. That is, when a fixed receiver clock error is used, the measured value of Equation 1 is transformed into the following Equation 28:

【equation 28】

$$\psi_i \equiv \Psi_i - cB_f = r_i + \nu_i,\ i=1,2,3$$

When Equation 28 is linearized, it becomes the following Equation 29:

【equation 29】

$$\delta\psi_i = h_i^T \delta p + \nu_i, \quad i=1,2,3$$

Also, with respect to 3 satellites, the following Equation 30 is obtained:

【equation 30】

$$\delta\psi = [\ h_1 \ \ h_2 \ \ h_3]^T \delta p + \nu \equiv G\delta p + \nu$$

Using a least squares method from Equation 30, the position can be obtained through Equation 31:

【equation 31】

$$\delta\hat{p} = G^{-1}\delta\psi$$

Here, since G is a square matrix, the same result as when using a weighted least squares method is obtained.

The altitude fixing method will be described as follows.

When the satellites travel in down-down areas or map information is provided, the altitude is little changed, thereby easily fixing the altitude. However, an obtained position is a value defined in the ECEF frame, so that we cannot know the altitude. accordingly, in order to fix the altitude, the position (x, y, z) in the ECEF frame must be changed to (1t, 1g, h) respectively indicating the latitude, the longitude, and the altitude in a longitudinal and latitudinal frame. This is accomplished through a coordinate conversion process

of the following Equation 32:

【equation 32】

$$x=(R_N+h)\cos(lt)\cos(\lg)$$

$$y=(R_N+h)\cos(lt)\sin(\lg)$$

$$z=(R_N(1-e^2)+h)\sin(lt)$$

Here, each parameter is defined as follows.

$f=\frac{1}{298.257223563}$: flatening defined in the WGS-84 frame

$e^2=1-(1-f)^2$: eccentricity defined in the WGS-84 frame

a=6378137: long radius defined in the WGS-84 frame

$R_N=\frac{a}{\sqrt{1-e^2\sin^2(lt)}}$: radius of curvature

The pseudorange measured value can be expressed by the longitudinal and latitudinal frame as the following Equation 33:

【equation 33】

$$\Psi_i=\sqrt{(X_i-x(lt,\lg,h))^2+(Y_i-y(lt,\lg,h))^2+(Z_i-z(lt,\lg,h))^2}+cB+\nu_i$$

Also, the Equation 33 is linearized with respect to a reference longitude and latitude $\chi_0=(lt0, \lg_0, h_0)$, to obtain the following Equation 34:

【equation 34】

$$\delta\Psi_i=g_i^T\begin{bmatrix}\delta lt\\ \delta\lg\\ \delta h\end{bmatrix}+cB+\nu_i\equiv g_i^T\delta\chi+cB+\nu_i$$

wherein g_i , being $[\frac{\partial \Psi_i}{\partial lt} \; \frac{\partial \Psi_i}{\partial \lg} \; \frac{\partial \Psi_i}{\partial lh}]^7$, indicates an initial line vector in the longitude and latitude frame. Here, $\frac{\partial \Psi_i}{\partial lt}$ is equal to $\frac{\partial \Psi_i}{\partial x}\frac{\partial x}{\partial lt}+\frac{\partial \Psi_i}{\partial y}\frac{\partial y}{\partial lt}+\frac{\partial \Psi_i}{\partial z}\frac{\partial z}{\partial lt}$, $\frac{\partial \Psi_i}{\partial \lg}$ is equal to $\frac{\partial \Psi_i}{\partial x}\frac{\partial x}{\partial \lg}+\frac{\partial \Psi_i}{\partial y}\frac{\partial y}{\partial \lg}+\frac{\partial \Psi_i}{\partial z}\frac{\partial z}{\partial \lg}$, and $\frac{\partial \Psi_i}{\partial h}$ is equal to $\frac{\partial \Psi_i}{\partial x}\frac{\partial x}{\partial h}+\frac{\partial \Psi_i}{\partial y}\frac{\partial y}{\partial h}+\frac{\partial \Psi_i}{\partial z}\frac{\partial z}{\partial h}$.

An initial line angle vector g_i in the longitude and latitude frame can be obtained using the relationship among the following Equations 36 through 39 obtained by using an initial line angle vector value $h_i=[\frac{\partial \Psi_i}{\partial x} \; \frac{\partial \Psi_i}{\partial y} \; \frac{\partial \Psi_i}{\partial z}]^7$ in the ECEF frame and the Equations 32 through 34:

【equation 36】

$$\frac{\partial R_N}{\partial lt} = \frac{a e^2 \sin(2lt)}{2(1-e^2\sin^2(lt))^{\frac{3}{2}}}$$

【equation 37】

$$\frac{\partial x}{\partial lt} = \frac{\partial R_N}{\partial lt}\cos(lt)\cos(\lg) - (R_N + h)\sin(lt)\cos(\lg)$$

$$\frac{\partial y}{\partial lt} = \frac{\partial R_N}{\partial lt}\cos(lt)\sin(\lg) - (R_N + h)\sin(lt)\sin(\lg)$$

$$\frac{\partial z}{\partial lt} = \frac{\partial R_N}{\partial lt}(1-e^2)\sin(lt) - (R_N(1-e^2)+h)\cos(lt)$$

【equation 38】

$$\frac{\partial x}{\partial \lg} = -(R_N + h)\cos(lt)\sin(\lg),\ \frac{\partial y}{\partial \lg} = (R_N + h)\cos(lt)\cos(\lg),\ \frac{\partial z}{\partial \lg} = 0$$

【equation 39】

$$\frac{\partial x}{\partial h} = \cos(lt)\cos(\lg),\ \frac{\partial y}{\partial h} = \cos(lt)\sin(\lg),\ \frac{\partial z}{\partial h} = \sin(lt)$$

Accordingly, the following Equation 40 with respect to m satellites is obtained, and the position and the receiver clock error can be obtained in the same way as Equation 5:

【equation 40】

$$\delta\Psi = \begin{bmatrix} g_1^T & 1 \\ \cdot & \cdot \\ \cdot & \cdot \\ g_m^T & 1 \end{bmatrix} \begin{bmatrix} \delta\chi \\ cB \end{bmatrix} + \nu$$

When 3 satellites are visible, the altitude can be fixed by using Equation 40, and the longitude, the latitude, and the receiver clock error can be obtained by the following Equation 41 in which an altitude has been removed:

【equation 41】

$$\begin{bmatrix} \delta\Psi_1 \\ \delta\Psi_2 \\ \delta\Psi_3 \end{bmatrix} = \begin{bmatrix} \frac{\partial\Psi_1}{\partial lt} & \frac{\partial\Psi_1}{\partial \lg} & 1 \\ \frac{\partial\Psi_2}{\partial lt} & \frac{\partial\Psi_2}{\partial \lg} & 1 \\ \frac{\partial\Psi_3}{\partial lt} & \frac{\partial\Psi_3}{\partial \lg} & 1 \end{bmatrix} \begin{bmatrix} \delta lt \\ \delta \lg \\ cB \end{bmatrix} + \nu$$

Once the position of the reference antenna is determined by the above-described method, a restriction that the length of a base line is known can be utilized as a new measured value in the attitude measurement, thereby obtaining the baseline vector even with only 3 satellites.

Two double-differenced carrier phase measurement expressions with respect to three satellites can be represented by the following Equalization 42:

【equation 42】

$$\begin{bmatrix} l_1-\lambda n_1 \\ l_2-\lambda n_2 \end{bmatrix} = \begin{bmatrix} h_{1x} & h_{1y} & h_{1z} \\ h_{2x} & h_{2y} & h_{2z} \end{bmatrix} \begin{bmatrix} r_x \\ r_y \\ r_z \end{bmatrix} + w$$

wherein n_1 and n_2 denote predetermined ambiguity integers. Additional conditions of the baseline can be expressed by the following Equation 43:

【equation 43】

$$b^2 = [\, r_x \;\; r_y \;\; r_z \,] \begin{bmatrix} r_x \\ r_y \\ r_z \end{bmatrix} + e$$

wherein ω is a carrier pahse measuring error, b is the length of a baseline, and e is a baseline length measuring error. Equations 42 and 43 can be expressed as the following Equation 44, and a baseline vector can be obtained from the nonlinear Equation 44:

【equation 44】

$$\begin{bmatrix} l_1-\lambda n_1 \\ l_2-\lambda n_2 \\ b^2 \end{bmatrix} = \begin{bmatrix} h_{1x} & h_{1y} & h_{1z} \\ h_{2x} & h_{2y} & h_{2z} \\ r_x & r_y & r_z \end{bmatrix} \begin{bmatrix} r_x \\ r_y \\ r_z \end{bmatrix} + \begin{bmatrix} w_1 \\ w_2 \\ e \end{bmatrix}$$

If the baseline vector is divided into $[\gamma_x \; \gamma_y]^T$ and γ_z to obtain the baseline vector in Equation 44, the following Equation 45 is obtained from Equation 42:

[equation 45]

$$\begin{bmatrix} r_x \\ r_y \end{bmatrix} = \begin{bmatrix} h_{1x} & h_{1y} \\ h_{2x} & h_{2y} \end{bmatrix}^{-1} \begin{bmatrix} l_1 - \lambda n_1 - h_{1z} r_z \\ l_2 - \lambda n_2 - h_{2z} r_z \end{bmatrix} \equiv H_2^{-1} \begin{bmatrix} l_1 - \lambda n_1 - h_{1z} r_z \\ l_2 - \lambda n_2 - h_{2z} r_z \end{bmatrix}$$

Also, the following Equation 46 is obtained using Equations 45 and 43.

[equation 46]

$$b^2 = [\ l_1 - \lambda n_1 - h_{1z} r_z \quad l_2 - \lambda n_2 - h_{2z} r_z]\, H_2^{-T} H_2^{-1} \begin{bmatrix} l_1 - \lambda n_1 - h_{1z} r_z \\ l_2 - \lambda n_2 - h_{2z} r_z \end{bmatrix} + r_z^2$$

r_z can be obtained using Equation 46, and $[\gamma_x \ \gamma_y]^T$ can be obtained using the r_z value. Here, since Equation 46 is a quadratic Equation, two baseline vectors are obtained. however, the two baseline vectors are compared to a baseline vector before visible satellites are three, and a baseline vector closer to the baseline vector before visible satellites are three is selected, thereby determining the solution.

[method of determining an attitude when the number of satellites is changed]

Now, a method of obtaining an attitude by rearranging satellites whose number is changed in step S5 will be described referring to FIG. 4A.

The step S8 is of determining whether four or more unchanged satellites remain when the number of satellites is changed. This step includes both the case that the number (m>4) of satellites is reduced to (m-1) and the case that it is increased to (m+1).

The step S9 is of rearranging satellites. Here, the satellites are arranged in various methods as follows according to the increase or decrease in satellites.

(the case that the number (m>4) of satellites is reduced to (m-1))

The ambiguity integers can be determined by rearranging the sequence of satellites with the exception of the reduced satellites. That is, ambiguity integers with respect to m satellites in the double differentiation expression are defined as in Equation 47:

【equation 47】

$$N_{AB}^{12}=N_{AB}^{2}-N_{AB}^{1}, N_{AB}^{23}=N_{AB}^{3}-N_{AB}^{2}, \cdots, N_{AB}^{(m-1)m}=N_{AB}^{m}-N_{AB}^{(m-1)}$$

In Equation 47, the left side indicates predetermined double-differenced ambiguity integers, and the right side indicates singl-differenced ambiguity integers. As shown in Equation 47, the single-differenced ambiguity integers are one more than the double-differenced ambiguity integers, so that they cannot be uniquely determined. However, the double-differenentiated ambiguity integers denotes relative differences of the singl-differenced ambiguity integers. Thus, if one of the single-differenced ambiguity integers is arbitrarily determined (e.g., N^{1}_{AB} is set to be 0), the remainders can be uniquely determined using the above Equation. Accordingly, arbitrary single-differenced ambiguity integers satisfying the above Equation can be easily determined, and for example, when a signal from a second satellite is blocked, (m-2) new ambiguity integers can be determined by the following Equation 48:

【equation 48】

$$N_{AB}^{13}=N_{AB}^{3}-N_{AB}^{1}, N_{AB}^{34}=N_{AB}^{4}-N_{AB}^{3}, \cdots, N_{AB}^{(m-1)m}=N_{AB}^{m}-N_{AB}^{(m-1)}$$

(the case that the number (m>4) of satellites is increased to (m+1))

Extra satellites are added to the end, and ambiguity integers are arranged as Equation 49:

【equation 49】

$$N_{AB}^{12}=N_{AB}^{2}-N_{AB}^{1}, \cdots, N_{AB}^{(m-1)m}=N_{AB}^{m}-N_{AB}^{(m-1)}, N_{AB}^{m(m+1)}=N_{AB}^{(m+1)}-N_{AB}^{m}$$

Also, the ambiguity integers are obtained by Equation 56 to be described later.

That is, satellites simultaneously tracked by the antennas A and B are arranged in the order of angles of elevation; and the above-described rearranging process is performed to minimize a change in satellites for determining independent ambiguity integers. Position dilution of precision (PDOP) is calculated by four satellites arranged in the above-described method. If the PDOP value is over 6, a satellite having the angle of elevation of next size is added. A combination of four satellites having a PDOP value of less than 6 is found from the five satellites and used. If the above process cannot be performed in lack of the number of satellites, the sequence is determined by using only the angle of elevation.

[method of determining an attitude when only two satellites are observed]

The step S10 is of determining whether observed satellites are two. Here, when the number of satellites is reduced but two satellites are contineously observed, even when the number of satellites is again increased, only one ambiguity integer can be additionally determined since one ambiguity integer is recognized. Accordingly, when only two satellites are observed, attitude determination is impossible, but in order to reduce a search range for the case that the number of satellites increases again, one double-differenced ambiguity integer corresponding to the two satellites and information on the two satellites are stored in step S11. Also, a situation where the attitude determination using a carrier phase is impossible is expressed to a user, and the user waits for the measured value of the next epoch, in step S12. here, a "end *" mark means an end situation of the case that the measured value of the next epoch must be used for attitude determination since the attitude determination is not completed.

Meanwhile, when at most one satellite is observed as the result of the change in satellites, the unknown intergers must be determined again from the beginning.

Then, an ambiguity resolution with constraint equation (ARCE) forming the basis of another embodiment of the present invention will be first described in detail beore this embodiment. the second embodiment will be described referring to FIGS. 4B, 4C, and 5.

[summary of ARCE]

First, it is assumed that at least 5 satellites can be observed by both a

reference station and a user, to induce the contranst equation.

A null space of H(t) in the double-differenced carrier phase measuring expressions given as Equations 20 and 21 is defined as E(t) by the following Equation 50:

【equation 50】

$$E(t)^T \cdot H(t) \equiv 0$$

When $E(t)^T$ is multiplied to both sides of Equation 21, the following Equation 51 is obtained, which is defined as a constraint Equation:

【equation 51】

$$E(t)^T l(t) = \lambda E(t)^T N + E(t)^T w(t)$$

H(t) is determined when a linearization nominal point of a receiver is set, and the linearization nominal point can be obtained using a code. The constraint Equation is formed regardless of a position $\delta x(t)$, and when m satellites are observed, $E(t)^T$ becomes a matrix of (m-3-1)×(m-1).

All ambiguity integers must satisfy a constraint Equation obtained at each epoch regardless of the position of the user. Accordingly, if using the above constraint Equation, the ambiguity integers can be searched without obtaining the position of the user, thereby easily accomplishing a OTF ambiguity integer search method.

For simple description, the constraint Equation 51 is simplified into the following Equation 52:

【equation 52】

$$l_E(t) = \lambda E(t)^T N + w_E(t), \qquad w_E(t) \sim N(0, E(t)^T Q_{D\Phi}(t) E(t)) \equiv N(0, Q_E(t))$$

wherein $l_E(t) \equiv E(t)^T l(t)$ and $\omega_E(t) \equiv E(t)^T \omega(t)$.

Determination of ambiguity integers using constraint Equation 52 can be defined as search for an ambiguity integer $N(\in Z^{m-1})$ for minimizing the object function of Equation 53 from the double-differenced carrier phases at up to n epoches with respect to m satellites.

【equation 53】

$$\Omega_{\Sigma E} \equiv \sum_{t=1}^{n} \Omega_E(t) = \sum_{t=1}^{n} \{(l_E(t) - \lambda E(t)^T N)^T Q_E(t)^{-1} (l_E(t) - \lambda E(t)^T N)\}$$

Hereinafter, determination of a dependent ambiguity integer term will be described.

In ambiguity integer determination, since an interpretative solution does not exist, object functions are obtained by substituting all possible unknown inter candidates within a given range, and an ambiguity integer giving a minimum value among the obtained object functions must be searched for. Accordingly, if a search range for each of (m-1) ambiguity integers with respect to m satellites is W, $W^{(m-1)}$ ambiguity integer candicates must be searched by reducing the ambiguity integer candidates as the object for search to reduce the amount of calculation and the memory for storage. this problem can be solved by using the constraint Equation. That is, only three of the (m-1) ambiguity integer terms can be recognized as independent by the following summary 1, and the independent ambiguity integer terms can be searched by using the above fact. Thus, only W^3 ambiguity integer candidates can be searched. Accordingly, the number of search target ambiguity integer candidates can be remarkably reduced, thus obtain a reduction in the amount of calculation and the storage memory.

(summary 1)

Only three of (m-1) ambiguity integers of the double-differenced carrier phase with respect to m (≥ 5) satellites are independent.

verification:

When an ambiguity integer candidate is divided into three arbitrary terms and the remainder in constant Equation 52 as follows, it can be expressed by the

following Equation 54:

【equation 54】

$$l_E(t)=[\,E_I^T(t)\quad E_D^T(t)]\begin{bmatrix}\lambda N_I\\ \lambda\,\tilde{N}_D\end{bmatrix}+w_E(t)=E_I^T(t)\lambda N_I+E_D^T(t)\lambda\,\tilde{N}_D+w_E(t)$$

wherein N_I is three arbitrary terms among ambiguity integers, $\tilde{N}_D$ the residual (m-1)-3 terms, $E_I^T(t)$ is a E(t) portion divided according to the definition of N_I, and $E_D^T(t)$ is a E(t) portion divided according to the definition of $\tilde{N}_D$.

Since $E_D^T(t)$ is a square matrix of ((m-1)-3)×((m-1)-3), (m-1)-3 residual ambiguity integer terms can be obtained by the following Equation 55:

【equation 55】

$$\lambda\tilde{N}_D=E_D^{-T}(t)(l_E(t)-E_I^T(t)\lambda N_I)$$

That is, only three of (m-1) ambiguity integer terms is independent.

On the basis of the summary 1, dependent ambiguity integers in (m-1)-3 integer region can be directly obtained by the following Equation 56:

【equation 56】

$$N_D=round(\,\tilde{N}_D)$$

In addition, the relation of the following Equation 57 can be obtained from the fact that $E^T(t)\cdot H(t)$ is zero:

【equation 57】

$$E_I^T(t)H_I(t)+E_D^T(t)H_D(t)=0$$

Also, $E_D^T(t)$ and $H_I(t)$ are square matrixes, and thus the following Equation 58 is formed:

【equation 58】

$$E_D^{-T}(t)E_I^T(t) = -H_D(t)H_I^{-1}(t)$$

Also, the position obtained by only the independent ambiguity integer terms can be expressed by the following Equation 59. Here, $H_I(t)$ is a square matrix, nd thus a weighted matrix is not shown.

【equation 59】

$$\delta\,\hat{x}_I(t) = H_I^{-1}(t)(l_I(t) - \lambda N_I)$$

wherein $l_I(t)$ is an $l(t)$ portion divided according to the definition of N_I.

Equation 55 can be expressed by the following Equation 60 using Equations 58 and 59:

【equation 60】

$$\lambda\,\tilde{N}_D = E_D^{-T}(t)\left(\begin{bmatrix} E_I^T(t) & E_D^T(t)\end{bmatrix}\begin{bmatrix} l_I(t) \\ l_D(t)\end{bmatrix} - E_I^T(t)\lambda N_I\right) = l_D(t) - H_D(t)\delta\,\tilde{x}_I(t)$$

It can be seen that Equation 60 is the same as determination of dependent ambiguity integers at a position obtained by the independent ambiguity integer terms from Equation 61. This indicates that the ARCE and LSAST are the same theorethically, but the ARCE can improve a search speed by reducing the amount of calculation since the dependent terms can be directly obtained with no need to obtain the position of a user by using Equation 55.

(definition of ambiguity integer search using dependent ambiguity integers)

The search is performed on independent ambiguity integer terms from the summary 1. Considering $\tilde{N} \equiv [N_I \;\; \tilde{N}_D]$ comprised of dependent ambiguity

integer terms in real number regions obtained with respect to each ambiguity integer candicate by Equation 55, the object function of Equation 53 is expressed by the following Equation 61:

【equation 61】

$$\Omega_E(t) = (l_E(t) - \lambda E_I^T(t) N_I - \lambda E_D^T(t)\ \widetilde{N}_D)^T Q_E^{-1}(t)(l_E(t) - \lambda E_I^T(t) N_I - \lambda E_D^T(t)\ \widetilde{N}_D)$$

$$=0$$

It can be seen from Equation 16 that an object function with respect to $\widetilde{N_D}$ in the real number region obtained using an independent ambiguity integer term N_I is zero. However, N_D in the integer region rather than $\widetilde{N_D}$ in the real number region is used in the search process, and $\widetilde{N_D}$ and N_D can be expressed by the following Equation 62:

【equation 62】

$$N_D \equiv \widetilde{N}_D + \delta N_D$$

Also, an object function is obtained using Equation 62, to become the following Equation 63:

【equation 63】

$$\Omega_E(t) = (\lambda E_D^T(t)\,\delta N_D)^T Q_E^{-1}(t)(\lambda E_D^T(t)\,\delta N_D) = \lambda^2 \delta N_D^T [E_D(t) Q_E^{-1}(t) E_D^T(t)]\,\delta N_D$$

It can be seen from Equation 63 that the object function $\Omega_E(t)$ for ambiguity integer determination is a barometer indicating the difference between the dependent ambiguity integer terms presumed in the real number region and those presumed in the integer region. The ambiguity integer determination can be expressed of only the dependent integer terms using Equation 63 as follows.

That is, the conclusion of this search is to search for an ambiguity

integer $N_I(\in Z^3)$ for minimizing the object function of Equation 63, from the double-differenced carrier phase at up to n epoches with respect to m satellites.

【equation 64】

$$\Omega_{\Sigma E} \equiv \sum_{t=1}^{n} \Omega_E(t) = \lambda^2 \sum_{t=1}^{n} \delta N_D^T(t)[E_D(t)Q_E^{-1}(t)E_D^T(t)]\delta N_D(t)$$

(determination of search range)

A double-differenced code and a double-differenced carrier phase including only the independent integer terms can be expressed respectively by the following Equations 65 and 66, and from this, the estimated values of ambiguity integers are expressed by the following Equation 67:

【equation 65】

$$\rho_I = H_I \delta x_I + \nu_I, \quad \nu_I \sim (0, Q_{D\Psi})$$

wherein ρ_I is a double-differenced code estimated value with respect to independent ambiguity integer term, H_I is an H portion divided by the independent ambiguity integer term, and ν_I is a double-differenced measured noise with respect to the independent ambiguity integer term. From here, a subscript (t) indicating time will not be described for convinence of representation.

【equation 66】

$$l_I = H_I \delta x_I + \lambda N_I + w_I, \quad w_I \sim N(0, Q_{D\Phi})$$

【equation 67】

$$\hat{N}_I = \frac{l_I - \rho_I}{\lambda}$$

Here, $Q_{D\Psi}$ is $\sigma^2_{\Psi}(DD \cdot DD^T)$, $Q_{D\Phi}$ is $\sigma^2_{\Phi}(DD \cdot DD^T)$, and a covariance of the estimated ambiguity integer becomes the following Equation 68:

【equation 68】

$$cov(\hat{N}_I) = \frac{cov(l_I - \rho_I)}{\lambda^2} = \frac{(\sigma^2_{\Psi} + \sigma^2_{\Phi})}{\lambda^2}(DD \cdot DD^T)$$

wherein σ^2_{Ψ} is the covariance of a code, and σ^2_{Φ} is the covariance of a carrier wave. when Equation 68 is rearranged by terms, it becomes the following Equation 69, and the search range is expressed by the following Equation 71:

【equation 69】

$$\begin{bmatrix} \sigma^2_{n_1} & \sigma_{n_1}\sigma_{n_2} & \sigma_{n_1}\sigma_{n_3} \\ \sigma_{n_1}\sigma_{n_2} & \sigma^2_{n_2} & \sigma_{n_2}\sigma_{n_3} \\ \sigma_{n_1}\sigma_{n_3} & \sigma_{n_2}\sigma_{n_3} & \sigma^2_{n_3} \end{bmatrix} = \frac{\sigma^2_{\Psi} + \sigma^2_{\Phi}}{\lambda^2} \begin{bmatrix} 4 & -2 & 0 \\ -2 & 4 & -2 \\ 0 & -2 & 4 \end{bmatrix}$$

【equation 70】

$$\hat{n}_i - \delta n_i \leq \hat{n}_i \leq \hat{n}_i + \delta n_i, \quad i = 1, 2, 3$$

wherein δ ni is $\beta \frac{2}{\lambda}\sqrt{\sigma^2_{\Psi} + \sigma^2_{\Phi}}$, and β is a significant level.

Then, let's consider Equation 71 as the carrier phase measurement expression with respect to 3 independent ambiguity integers, in which a linearization nominal point is set as a reference antenna to change a restriction on the baseline length into a restriction on the ambiguity integers. When the baseline vector is obtained using the least square method from Equation 71, it is expressed by the following Equation 72, and the restriction on the baseline length is expressed by the following Equation 73:

【equation 71】

$$l_I = H_I r_I + \lambda N_I + w_I$$

【equation 72】

$$\hat{r}_I = H^{-1}{}_I (l_I - \lambda N_I)$$

【equation 73】

$$b^2 = \hat{r}_I{}^T \hat{r}_I = (l_I - \lambda N_I)^T H_I{}^{-T} H_I{}^{-1} (l_I - \lambda N_I)$$

In Equation 73, $H_I H_I^T$ is LL^T by Cholesky decomposition, so that Equation 73 can be expressed in the forme of vector times as in Equation 74:

【equation 74】

$$b^2 = [L^{-1} (l_I - \lambda N_I)]^T [L^{-1} (l_I - \lambda N_I)]$$

Also, since L^{-1} is a low triangular matrix, it can be defined as the following Equation 75:

【equation 75】

$$L^{-1} = \begin{bmatrix} x_{11} & 0 & 0 \\ x_{21} & x_{22} & 0 \\ x_{31} & x_{32} & x_{33} \end{bmatrix}$$

Here, when the independent ambiguity integer term N_I is set to be $[n_1\ n_2\ n_3]^T$, the following Equation 76 is formed:

【equation 76】

$$L^{-1}(l - \lambda N) \equiv \begin{bmatrix} \gamma_1 \\ \gamma_2 \\ \gamma_3 \end{bmatrix} = \begin{bmatrix} x_{11} (l_1 - \lambda n_1) \\ x_{21} (l_1 - \lambda n_1) + x_{22} (l_2 - \lambda n_2) \\ x_{31} (l_1 - \lambda n_1) + x_{32} (l_2 - \lambda n_2) + x_{33} (l_3 - \lambda n_3) \end{bmatrix}$$

Accordingly, the restriction on length is expressed by the following Equation 77:

【equation 77】

$$b^2 = \gamma_1^2 + \gamma_2^2 + \gamma_3^2$$

$-b \le \gamma_1 \le b$, and $-\sqrt{b^2-\gamma_1^2} \le \gamma_2 \le \sqrt{b^2-\gamma_1^2}$ are formed from Equation 77, and if these relational expressions are to be represented with respect to the ambiguity integers, they becomes the following Equations 78 and 79:

【equation 78】

$$-\frac{b}{\lambda x_{11}} + \frac{l_1}{\lambda} \le n_1 \le \frac{b}{\lambda x_{11}} + \frac{l_1}{\lambda}$$

【equation 79】

$$-\frac{\sqrt{b^2-\gamma_1^2}}{\lambda x_{22}} + \xi_1 \le n_2 \le \frac{\sqrt{b^2-\gamma_1^2}}{\lambda x_{22}} + \xi_1$$

wherein $\xi_1 \equiv \frac{x_{21}(l-\lambda n_1)+x_{22} l_2}{\lambda x_{22}}$ is given.

The range of n_1 determined by using both the covariance information and the baseline length is expressed by the following Equation 80:

【equation 80】

$$\max(\hat{n}_1 - \delta n_1, \frac{-b}{\lambda x_{11}} + \frac{l_1}{\lambda}) \le n_1 \le \min(\hat{n}_1 + \delta n_1, \frac{b}{\lambda x_{11}} + \frac{l_1}{\lambda})$$

The range of n_2 can also be obtained from the covariance information and geometrical information in the same method as in the case of n_1, and n_3 with respect to the ambiguity integer candidates n_1 and n_2 can be obtained from

Equation 77 by the following Equation 81:

【equation 80】

$$\max(\hat{n}_1 - \delta n_1, \frac{-b}{\lambda x_{11}} + \frac{l_1}{\lambda}) \le n_1 \le \min(\hat{n}_1 + \delta n_1, \frac{b}{\lambda x_{11}} + \frac{l_1}{\lambda})$$

wherein $\xi_2 \equiv \frac{x_{31}(l_1 - \lambda n_1) + x_{32}(l_2 - \lambda n_2) + x_{33} l_3}{\lambda x_{33}}$ is given.

Here, a negative value in a square root even with respect to a true known integer may be generated under the influence of the measured noise during the calculations of Equations 79 and 81. In order to prevent this problem, the calculations are performed after the baseline length is set to be b′ =b+b$_\varepsilon$. in this embodiment, b$_\varepsilon$ is expressed by the following Equation 82:

【equation 82】

$$b_\varepsilon = \alpha\sqrt{2} q_N \sigma$$

wherein α is a significant level of about 3, q_N is an experimental average value of about 1, and σ is a carrier phase measured noise which is determined according to the performance fo a receiver.

(previous calculation of variables necessary for ambiguity integer search)

When an obtained search range is searched, parameters not changing during search are previously calculated to reduce the amount of calculation.

That is, in order to calculate $\lambda \overline{N_D} = E_D^{-T}(t)(l_E(t) - E_I^T(t)\lambda N_I)$, $l_E(t)$, $\frac{E_D^{-T}(t)}{\lambda}$, and $E_I^T(t)$ are previously calculated. in order to calculate $\Omega_E(t) = \lambda^2 \delta N_D^T[E_D(t) Q_E^{-1}(t) E_D^T(t)] \delta N_D$, $\lambda^2[E_D(t) Q_E^{-1}(t) E_D^T(t)]$ is previously calculated.

Also, for calculation of $-\frac{b}{\lambda x_{11}} + \frac{l_1}{\lambda} \le n_1 \le \frac{b}{\lambda x_{11}} + \frac{l_1}{\lambda}$, $L^{-1} = \begin{bmatrix} x_{11} & 0 & 0 \\ x_{21} & x_{22} & 0 \\ x_{31} & x_{32} & x_{33} \end{bmatrix}$, being a lower triangular matrix, is previously calculated.

For calcualtion of $\widehat{N_D^*} = \widehat{N_D} - E_D^{-T} E_I^T \begin{bmatrix} 0 \\ 0 \\ \pm 1 \end{bmatrix}$,

$E_D^{-T} E_I^T \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}$, $E_D^{-T} E_I^T \begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix}$, and $E_D^{-T} E_I^T \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix}$ are previously calculated.

(search for ambiguity integers)]

For simple representation, pre-calculated variable values are first defined as follows.

$$le \equiv l_E(t),\ \ ied \equiv \frac{E_D^{-T}(t)}{\lambda},\ \ ei \equiv E_I^T(t),\ \ Pee \equiv \lambda^2 [E_D(t) Q_E^{-1}(t) E_D^T(t)]$$

$$iL \equiv L^{-1} = \begin{bmatrix} x_{11} & 0 & 0 \\ x_{21} & x_{22} & 0 \\ x_{31} & x_{32} & x_{33} \end{bmatrix}$$

$$e3 \equiv E_D^{-T} E_I^T \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix},\ \ e2 \equiv E_D^{-T} E_I^T \begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix},\ \ e1 \equiv E_D^{-T} E_I^T \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix}$$

$$N\_init(i) = round(\ \widehat{N}_I\ ) = round(\frac{l_I - \rho_I}{\lambda})$$

δn_1, δn_2, δn_3 : search ranges due to covariance

$$n1\_m \equiv \max(\ \hat{n}_1 - \delta n_1, \frac{-b}{\lambda x_{11}} + \frac{l_1}{\lambda}) \le n_1 \le \min(\ \hat{n}_1 + \delta n_1, \frac{b}{\lambda x_{11}} + \frac{l_1}{\lambda}) \equiv n1\_M$$

$b' = b + b_\varepsilon$: baseline length determined by Equation 82 in consideration of error

$$g1 = b'^2 - \gamma_1^2,\ \ \ g2 = b'^2 - \gamma_1^2 - \gamma_2^2$$

Hereinafter, a process for searching ambiguity integers when the ambiguity integers are not determined will be described referring to FIG. 4C.

The initial step ⓐ in FIG. 4C is of rearranging satellites and searching for ambiguity integers when a cycle slip occurs even when the ambiguity integers

have been determined, or when the ambiguity integers are not determined, in FIG. 4A.

The step S13 is of determining whether an ambiguity integer already obtained exists before search for the ambiguity integers is started. Just before the number of satellites is changed, two satellites have been observed. If the cycle slip did not occur with respect to the signal, the ambiguity integers with respect to a corresponding satellite are considered as being alrealy known. The search for the ambiguity integers starts when at least 5 satellites are observed.

If it is determined in step S13 that an ambiguity integer already recognized exists, this is the case that two satellites are continuously tracked without being changed. Thus, in this case, two corresponding satellites are placed at the head, and the remaining satellites are rearranged, in step S14.

The method of arranging the order of satellites includes the steps of: selecting the remaining satellites in the sequence of angles of elevation; determining whether a PDOP value calculated by the two fixed satellites and the other satellites selected in the sequence of angles of elevation is greater than 6; and arranging the four selected satellites in the sequence of elevations if the PDOP value is not greater than 6, and additionally selecting a satellite having an elevation of next size, extracting a combination of four satellites in which the PDOP value calculated by the five selected satellites is equal to or smaller than 6, and arranging the satellites in the order of elevations, if the PDOP value exceeds 6.

On the other hand, if it is determined in step S13 that an ambiguity integer already recognized does not exist, five or more satellites are arranged in step S15. This method is the same as the satellite arranging process in step S9.

When the satellites are completely arranged, a search range for the ambiguity integers is determined using the restrictive conditions such as covariance information and baseline length. This process was already described in the section of (determination of search range).

In step S17, parameters not changing during search are previously calculated to reduce the amount of calculation.

The step ⓢ is of searching for ambiguity integers, the step S18 is of determining whether search is completed, and the step S19 is of calculating an

object function and storing ambiguity integer candidate values only when the object function is smaller than a predetermined critical value.

The step ⓢ, and the steps S18 and S19 will now be described referring to FIG. 5 illustrating a process for searching for ambiguity integers.

In FIG. 5, the step D1 is of determining whether this is the first search. if the ambiguity integers are searched but not determined at a previous epoch, the procedure goes to the step D23. If this is the first search, the procedure goes to the step D2 of determining whether one ambiguity integer n_1 is already recognized. If one ambiguity integer n_1 is already recognized, n_1 can be fixed with no need to be searched. That is, in this step, a previous value of n_1 is restored, and $n_1\_m = n_1\_M = n_1$ can be given.

Meanwhile, if no ambiguity integers is not recognized, search of n_1 is performed in step D4. The range of an integer n_1 is determined as $N\_init(1)+n_1\_m \leq n_1 \leq N\_init(1)+n_1\_M$.

The next step D5 is of determining whether $g1(=b^{'2}-\gamma_1^2)$ is negative. If g1 is negative, a negative value enters the square root, and thus the ambiguity integers cannot be searched. If g1 is not negative, n_2 is searched in step D6.

Since the range of n_2 depending on the restrictive conditions of the baseline length is given as $n_2\_bm \equiv \frac{-\sqrt{g1}}{\lambda x_{22}} + \xi_1 \leq n_2 \leq \frac{\sqrt{g1}}{\lambda x_{22}} + \xi_1 \equiv n_2\_bM$, the range of n_2 is given as $n_2\_m \equiv \max(\widehat{n}_2 - \delta n_2,\ n_2\_bm) \leq n_2 \leq \min(\widehat{n}_2 + \delta n_2,\ n_2\_bM) \equiv n_2\_M$. Here, ξ_1 is equal to $\frac{x_{21}(l_1-\lambda n_1)+x_{22}l_2}{\lambda x_{22}}$. Accordingly, the range of the integer n_2 is given as $N\_init(2)+n_2\_m \leq n_2 \leq N\_init(2)+n_2\_M$.

The next step D7 is of determining whether $g2(=b^{'2}-\gamma_1^2-\gamma_2^2)$ is negative. If g2 is negative, the negative value enters the square root, and thus the ambiguity integers cannot be searched. If g2 is not negative, n_3 is searched in step D8.

When n_3 defines a close integer value with $n_3\_bm \equiv round(\frac{-\sqrt{g_2}}{\lambda x_{33}} + \xi_2)$ and $n_3\_bM \equiv round(\frac{\sqrt{g_2}}{\lambda x_{33}} + \xi_2)$, n_3 is searched with respect to an integer value of $N\_init(3)-n_3\_bm-1 \leq n_3 \leq N\_init(3)-n_3\_bm+1$ and $N\_init(3)-n_3\_bM-1 \leq n_3 \leq$

N_*init*(3)-n_3_bM+1. Absolutely, n_3 is also searched with respect to the residual excluding values deviating from the range of covariance. When an integer value of n_3 is defined, ξ_2 is equal to $\frac{x_{31}(l_1-\lambda n_1)+x_{32}(l_2-\lambda n_2)+x_{22}l_3}{\lambda x_{33}}$.

When independent ambiguity integers n_1, n_2, and n_3 are searched, the matrix for the independent ambiguity integers NI is determined as $\begin{bmatrix} n_1 \\ n_2 \\ n_3 \end{bmatrix}$ in step D9. Maximum 6 n_3 can be selected by searching, with respect to a fixed n_1.

In the next step D10, a determination of whether information on $\widetilde{N}_D$ exists is made. If no information on $\widetilde{N}_D$ exists, $\widetilde{N}_D$ is set to be *ied(le-ei* · N_I), and is stored as the $\widetilde{N}_D$ value together with the independent ambiguity integer NI. Here, $\widetilde{N}_D$ deviating from the covariance range is deserted.

Meanwhile, if information on $\widetilde{N}_D$ exists, $\widetilde{N}_D$ corresponding to a corresponding N_I is selected in step D12. Here, values deviating from the covariance range are deserted. when n_3, n_2, and n_1 are changed respectively in steps D13, D14 and D16, $\widetilde{N}_D$ is changed by a changed value as much as a value corresponding to each basis and then stored. accordingly, the operations of $\widetilde{N}_D = \widetilde{N}_D \pm e3$, $\widetilde{N}_D = \widetilde{N}_D \pm e2$, and $\widetilde{N}_D = \widetilde{N}_D \pm e1$ are performed respectively in steps D15, D17, and D18.

When dependent ambiguity integer search is completed, an operation of $\delta N_D = \widetilde{N}_D - round(\widetilde{N}_D)$ is performed in step D19. After an operation of $\delta\Omega(N_I) = \delta N_D^T \cdot Pee \cdot N_D$ is performed in step D20, $\delta\,\Omega(N_I)$ is compared to a predetermined critical value χ in step D21. If $\delta\,\Omega(N_I)$ is smaller than the critical value, a sum of $\Omega(N_I)$ and $\delta\,\Omega(N_I)$ is stored in a new $\Omega(N_I)$, and N_I in this case is stored, in step D22.

On the other hand, if it is determined in step D1 this is not the first search, the same process as in the steps D11, D19, D21 and D22 is performed on only the values left after search at the previous epoch is performed.

Now, a process for determining ambiguity integer candidate values will be described referring to FIG. 4D.

When ambiguity integer search is completed as in step ⓐ, the number of ambiguity integer candidates is determined in step S20. When only one ambiguity integer candidate remains, this is fixed as a true value, and the attitude of a navigating body is determined in step S21. when no ambiguity integer candidates remain, the search must be started again. When the number of ambiguity integer candidates is 2 or more, ratio inspection is made in step S22. The ratio inspection must be made using the fact that an ambiguity integer minimizing a given object function rather than the other ambiguity integers must give a significantly small object function. Also, the ratio inspection uses the following Equation 83:

【equation 83】

$$\frac{\Omega_{2nd}}{\Omega_{1st}} \geq threshold\ \tau$$

wherein Ω_{1st} is a minimum object function and Ω_{2nd} is a second minimum object function. This ratio inspection starts when the number rate of left candidates among a total of candidates is 10% or less. The critical value is usually between 1.5 and 7. If the ambiguity integer candidates pass the inspection, they are fixed as true ambiguity integers, and then the attitude is determined in step S21. Otherwise, continuous search must be performed using the next measured value since the determination of the ambiguity integers fails under the influence of measured noise. The process for performing another search starts from the step S23 of receiving another epoch data item. In the next step S24, a determination of whether the number of satellites is changed is made, and if there is any change, it is determined whether any ambiguity integer candidate value exists. If there is no ambiguity integer value, attitude determination cannot be conducted. If there is any ambiguity integer value, it is determined whether the independent ambiguity integer was affected in spite of a change in the number of satellites, in step S26. If it was affected, the search for ambiguity integers must start again from the beginning. If satellites for the independent ambiguity integers are continuously tracked without change in the number of satellites, the search for ambiguity integers can be continuously

performed. Accordingly, since four satellites are already fixed, they are set as satellites for independent ambiguity integers, and the other satellites are arranged in the order of angles of elevation, in step S27.

Not only when there is no change in satellites but also when the satellites are rearranged, an epoch data item is further received. Thus, in step S28, common parameters are calculated again, and search for ambiguity integers is then performed. However, the ambiguity integer search in this case means search for only ambiguity integer candidates left during the already-performed ambiguity integer search. This process is performed in the steps D23, D24, and D25 of FIG. 5.

When the ambiguity integers are determined through these processes, the attitude of a naviating body can be determined using the determined ambiguity integers.

According to the present invention, a search range for ambiguity integers can be reduced, and the amount of calculation with respect to each ambiguity integer candidate within the search range can be minimized, to obtain the ambiguity integers in real time: also, the ambiguity integers can be consecutively determined even when blocking of a satellite signal occurs in real circumstances. However, if the ambiguity integers have been already determined, they are continuously used as long as possible, and thus the attitude can be obtained using the obtained ambiguity integers and phase measured values. When the ambiguity integers have been determined, the attitude can be continuously obtained even in the case of 3 satellites.

Accordingly, the amount of calculation necessary for searching for the ambiguity integers can be significantly reduced, so that the attitude of a navigating body can be determined in real time. Also, the ambiguity integers are robustly determined even upon blocking of the satellite signal which may occur in real operating circumstances, thus determining the attitude of a naviating body. Thus, this method is variously applicable to control of the orbit and attitude of satellites, entry of airplanes into the runway, operation of ships, arrangement upon flying, operation of vehicles, etc.

WHAT IS CLAIMED IS:

1. A method for determining the attitude of a vehicle using GPS carrier signals transmitted by a plurality of satellites, the method comprising the steps of:

(1) providing known baseline length(s) for at least two antennas including a reference antenna which are mounted on the vehicle and preparing coefficients for coordinate transformation between the WGS-84 frame and the navigation frame;

(2) receiving GPS code and phase signals by the antennas at an epoch in order to obtain pseudoranges by processing the received signals using time-synchronized receiver channels, and then transferring the pseudoranges to a microcomputer unit;

(3) deciding at every epoch whether the number of satellites is more than four;

(4) in case that the number of satellites is more than four, determining the position of a reference antenna using GPS code measurements of the satellites at the microcomputer unit;

(5) deciding whether ambiguity integers of the GPS carrier phase signals are determined;

(6) in case that the ambiguity integers are determined, deciding whether there is a change in the number of the satellites by comparing the numbers of the satellites commonly observed by the antennas at consecutive two epochs;

(7) in case of no change in the number of the satellites, comparing a criterion function $\Omega_E(t)$ obtained from the determined ambiguity integers to a threshold $x(t)(\equiv \alpha^2\lambda^2\nu^T[E_D(t)Q_E^{-1}(t)E_D^T(t)]\nu)$ and then deciding the occurrence of a cycle slip when $\Omega_E(t) > x(t)$;

(8) in case of no cycle slip, providing a plurality of baseline vectors in the WGS-84 frame by obtaining the relative positions of remaining antennas to

the reference antenna from the carrier phase measurement using the determined ambiguity integers; and

(9) defining the position of the reference antenna as the origin of the vehicle body frame and transforming the multiple baseline vectors of the WGS-84 frame to vectors of the navigation frame using the prepared coefficients.

2. The method of claim 1, wherein the α is in the range of 0.05 to 0.1.

3. A method for determining the attitude of a vehicle using GPS carrier phase transmitted by a plurality of satellites, the method comprising the steps of:

(1) providing known baseline length(s) for at least two antennas including a reference antenna which are mounted on the vehicle and preparing coefficients for coordinate transformation between the WGS-84 frame and the navigation frame;

(2) receiving GPS code and phase signals by the antennas at an epoch in order to obtain pseudoranges by processing the received signals using time-synchronized receiver channels, and then transferring the pseudoranges to a microcomputer unit;

(3) deciding at every epoch whether the number of satellites is more than four;

(4) in case that the number of satellites changed from more than four to three, determining the position of a reference antenna at the microcomputer unit using GPS code measurements of the satellites with one minimum-change parameter fixed;

(5) deciding whether ambiguity integers of the GPS carrier phase signals are determined;

(6) in case that the ambiguity integers are determined, obtaining two baseline vectors for each remaing antennas to the reference antenna by

substituting the baseline lengths and ambiguity integers into two double-differenced carrier phase measurements for the three satellites;

(7) selecting baseline vectors from the respective two baseline vectors, which is closer to the baseline vector obtained just before the number of satellites changed to three; and

(8) transforming the selected baseline vectors to those of the navigation frame using the prepared coefficients.

4. The method of claim 3, wherein the fixed one parameter in the GPS code measurement is a clock error of the receivers.

5. The method of claim 3, wherein the fixed one parameter in the GPS code measurement is an altitude.

6. A method for determining the attitude of a vehicle using GPS carrier phase transmitted by a plurality of satellites, the method comprising the steps of:

(1) providing known baseline length(s) for at least two antennas including a reference antenna which are mounted on the vehicle and preparing coefficients for coordinate transformation between the WGS-84 frame and the navigation frame;

(2) receiving GPS code and phase signals by the antennas at an epoch in order to obtain pseudoranges by processing the received signals using time-synchronized receiver channels, and then transferring the pseudoranges to a microcomputer unit;

(3) deciding at every epoch whether the number of satellites is more than four;

(4) in case that the number of satellites is more than four, determining the position of a reference antenna using GPS code measurements of the satellites at the microcomputer unit;

(5) deciding whether ambiguity integers of the GPS carrier phase signals

are determined;

(6) in case that the ambiguity integers are determined, deciding whether there is a change in the number of the satellites by comparing the numbers of the satellites commonly observed by the antennas at consecutive two epochs;

(7) in case that the number m(m>4) of satellites changed to m-1, determing m-2 new double-differenced ambiguity integers by rearranging the order of the satellites and then by selecting any one from single--differenced ambiguity integers;

(8) comparing a criterion function $\Omega_E(t)$ obtained from the determined ambiguity integers to a threshold $x(t)(\equiv \alpha^2\lambda^2\nu^T[E_D(t)Q_E^{-1}(t)E_D^T(t)]\nu)$ and then deciding the occurrence of a cycle slip when $\Omega_E(t) > x(t)$;

(9) in case of no cycle slip, providing a plurality of baseline vectors in the WGS-84 frame by obtaining the relative positions of remaining antennas to the reference antenna from the carrier phase measurement using the determined ambiguity integers; and

(10) defining the position of the reference antenna as the origin of the vehicle body frame and transforming the multiple baseline vectors of the WGS-84 frame to vectors of the navigation frame using the prepared coefficients.

7. The method of claim 6, wherein the α is in the range of 0.05 to 0.1.

8. The method of claim 6, wherein the method of rearranging the order of the satellite in the (7)th step comprises the steps of:

(7-1) choosing four satellites in the order of elevation angles;

(7-2) deciding whether the PDOP value calculated from the four satellites exceeds 6; and

(7-3) in case that the PDOP value does not exceed 6, arranging the four satellites in the order of elevation angles.

9. The method of claim 6, wherein the method of rearranging the order of the satellite in the (7)th step comprises the steps of:

(7-1) choosing four satellites in the order of elevation angles;

(7-2) deciding whether the PDOP value calculated from the four satellites exceeds 6;

(7-3) in case that the PDOP value exceeds 6, choosing one more satellite having the next largest elevation angle, and then extracting four satellites to make PDOP value less than 6; and

(7-4) arranging the extracted four satellites in the order of elevation angles.

10. A method for determining the attitude of a vehicle using GPS carrier phase transmitted by a plurality of satellites, the method comprising the steps of:

(1) providing known baseline length(s) for at least two antennas including a reference antenna which are mounted on the vehicle and preparing coefficients for coordinate transformation between the WGS-84 frame and the navigation frame;

(2) receiving GPS code and phase signals by the antennas at an epoch in order to obtain pseudoranges by processing the received signals using time-synchronized receiver channels, and then transferring the pseudoranges to a microcomputer unit;

(3) deciding at every epoch whether the number of satellites is more than four;

(4) in case that the number of satellites is more than four, determining the position of a reference antenna using GPS code measurements of the satellites at the microcomputer unit;

(5) deciding whether ambiguity integers of the GPS carrier phase signals are determined;

(6) in case that the ambiguity integers are determined, deciding whether there is a change in the number of the satellites by comparing the numbers of the satellites commonly observed by the antennas at consecutive two epochs;

(7) in case that the number m(m>4) of satellites changed to m+1, determing added new double-differenced ambiguity integers by rearranging the order of the satellites so that the added satellite is ordered to be the last;

(8) comparing a criterion function $\Omega_E(t)$ obtained from the determined ambiguity integers to a threshold $\chi(t)(\equiv \alpha^2\lambda^2\nu^T[E_D(t)Q_E^{-1}(t)E_D^T(t)]\nu)$ and then deciding the occurrence of a cycle slip when $\Omega_E(t) > \chi(t)$;

(9) in case of no cycle slip, providing a plurality of baseline vectors in the WGS-84 frame by obtaining the relative positions of remaining antennas to the reference antenna from the carrier phase measurement using the determined ambiguity integers; and

(10) defining the position of the reference antenna as the origin of the vehicle body frame and transforming the multiple baseline vectors of the WGS-84 frame to vectors of the navigation frame using the prepared coefficients.

11. The method of claim 10, wherein the α is in the range of 0.05 to 0.1.

12. A method for determining the attitude of a vehicle using GPS carrier phase transmitted by a plurality of satellites, the method comprising the steps of:

(1) providing known baseline length(s) for at least two antennas including a reference antenna which are mounted on the vehicle and preparing coefficients for coordinate transformation between the WGS-84 frame and the navigation frame;

(2) receiving GPS code and phase signals by the antennas at an epoch in order to obtain pseudoranges by processing the received signals using time-synchronized receiver channels, and then transferring the pseudoranges to a

microcomputer unit;

(3) deciding at every epoch whether the number of satellites is more than four;

(4) in case that the number of satellites is more than four, determining the position of a reference antenna using GPS code measurements of the satellites at the microcomputer unit;

(5) deciding whether ambiguity integers of the GPS carrier phase signals are determined;

(6) in case that the ambiguity integers are determined, deciding whether there is a change in the number of the satellites by comparing the numbers of the satellites commonly observed by the antennas at consecutive two epochs;

(7) in case that only two satellites are commonly observed, storing one double-differenced ambiguity integer and satellite information for the two observed satellites in order to reduce the search range when the number of satellites increases.

13. A method for determining the attitude of a vehicle using GPS carrier phase transmitted by a plurality of satellites, the method comprising the steps of:

(1) providing known baseline length(s) for at least two antennas including a reference antenna which are mounted on the vehicle and preparing coefficients for coordinate transformation between the WGS-84 frame and the navigation frame;

(2) receiving GPS code and phase signals by the antennas at an epoch in order to obtain pseudoranges by processing the received signals using time-synchronized receiver channels, and then transferring the pseudoranges to a microcomputer unit;

(3) deciding at every epoch whether the number of satellites is more than four;

(4) in case that the number of satellites is more than four, determining the position of a reference antenna using GPS code measurements of the satellites at the microcomputer unit;

(5) in case that ambiguity integers of the GPS carrier phase signals are not determined, deciding whether any known one of the ambiguity integers can be used;

(6) in case that any known ambiguity integer can not be used, selecting more than five observed satellites in the order of elevation angles, and then arranging the satellites on the basis of the PDOP values of their respective arrangement;

(7) determining the search range of independent ambiguity integers(n_1 and n_2) and n_3 as follows by using the covariance estimated from the double-differenced code and carrier phase equations including only independent ambiguity integer term as well as the constraint that the baseline lengths are invariant;

$$\max(\hat{n}_1 - \delta n_1, \frac{-b}{\lambda x_{11}} + \frac{l_1}{\lambda}) \leq n_1 \leq \min(\hat{n}_1 + \delta n_1, \frac{b}{\lambda x_{11}} + \frac{l_1}{\lambda})$$

$$\max(\widehat{n_2} - \delta n_2, \frac{-\sqrt{g_1}}{\lambda x_{22}} + \xi_1) \leq n_2 \leq \min(\widehat{n_2} + \delta n_2, \frac{\sqrt{g_1}}{\lambda x_{22}} + \xi_1)$$

$$n_3 = \frac{\pm\sqrt{g_2}}{\lambda x_{33}} + \xi_2$$

(8) preparing the calculated parameters necessary for the search of the independent ambiguity integers;

(9) searching the independent ambiguity integers by the ARCE method within the search range to calculate δN_D, and then accumulating $\delta\Omega(N_I)$ defined from the δN_D only in case that $\delta\Omega(N_I)$ is less than a predetermined threshold, calculating cost function $\Omega(N_I)$ and storing ambiguity integer candidates;

(10) deciding whether the number of the ambiguity integer candidates are more than two;

(11) in case that the number of the ambiguity integer candidates is one, fixing it as a true value and providing a plurality of baseline vectors in the WGS-84 frame by obtaining the relative positions of remaining antennas to the reference antenna from the carrier phase measurement using the determined ambiguity integers;

(12) defining the position of the reference antenna as the origin of the vehicle body frame and transforming the multiple baseline vectors of the WGS-84 frame to vectors of the navigation frame using the prepared coefficients.

14. The method of claim 13, wherein the value b is substituted by a value b' which is increased by a predetermined value b_{ε} to avoid the result that the upper and lower bounds of the search range become imaginary values in case that g1 and g2 values inside the square root of the (7)th step become negative due to the measurement error of baseline length.

15. The method of claim 13, wherein the method of arranging the order of the satellite in the (6)th step comprises the steps of:

(6-1) choosing four satellites in the order of elevation angles for more than five satellites;

(6-2) deciding whether the PDOP value calculated from the four satellites exceeds 6; and

(6-3) in case that the PDOP value does not exceed 6, arranging the four satellites in the order of elevation angles.

16. The method of claim 13, wherein the method of arranging the order of the satellite in the (6)th step comprises the steps of:

(6-1) choosing four satellites in the order of elevation angles for more than five satellites;

(6-2) deciding whether the PDOP value calculated from the four satellites exceeds 6; and

(6-3) in case that the PDOP value exceeds 6, choosing one more satellite having the next largest elevation angle, and then extracting four satellites to make PDOP value less than 6; and

(6-4) arranging the extracted four satellites in the order of elevation angles.

17. A method for determining the attitude of a vehicle using GPS carrier phase transmitted by a plurality of satellites, the method comprising the steps of:

(1) providing known baseline length(s) for at least two antennas including a reference antenna which are mounted on the vehicle and preparing coefficients for coordinate transformation between the WGS-84 frame and the navigation frame;

(2) receiving GPS code and phase signals by the antennas at an epoch in order to obtain pseudoranges by processing the received signals using time-synchronized receiver channels, and then transferring the pseudoranges to a microcomputer unit;

(3) deciding at every epoch whether the number of satellites is more than four;

(4) in case that the number of satellites is more than four, determining the position of a reference antenna using GPS code measurements of the satellites at the microcomputer unit;

(5) in case that ambiguity integers of the GPS carrier phase signals are not determined, deciding whether any known one of the ambiguity integers can be used;

(6) in case that any known ambiguity integer can not be used, selecting more than five observed satellites in the order of elevation angles, and then

arranging the satellites on the basis of the PDOP values of their respective arrangement;

(7) determining the search range of independent ambiguity integers(n_1 and n_2) and n_3 as follows by using the covariance estimated from the double-differenced code and carrier phase equations including only independent ambiguity integer term as well as the constraint that the baseline lengths are invariant;

$$\max(\hat{n}_1 - \delta n_1, \frac{-b}{\lambda x_{11}} + \frac{l_1}{\lambda}) \le n_1 \le \min(\hat{n}_1 + \delta n_1, \frac{b}{\lambda x_{11}} + \frac{l_1}{\lambda})$$

$$\max(\hat{n}_2 - \delta n_2, \frac{-\sqrt{g_1}}{\lambda x_{22}} + \xi_1) \le n_2 \le \min(\hat{n}_2 + \delta n_2, \frac{\sqrt{g_1}}{\lambda x_{22}} + \xi_1)$$

$$n_3 = \frac{\pm\sqrt{g_2}}{\lambda x_{33}} + \xi_2$$

(8) preparing the calculated parameters necessary for the search of the independent ambiguity integers;

(9) searching the independent ambiguity integers by the ARCE method within the search range to calculate δN_D, and then accumulating $\delta \Omega(N_I)$ defined from the δN_D only in case that $\delta \Omega(N_I)$ is less than a predetermined threshold, calculating cost function $\Omega(N_I)$ and storing ambiguity integer candidates;

(10) deciding whether the number of the ambiguity integer candidates are more than two;

(11) in case that the number of the ambiguity integer candidates is more than two, fixing one as a true value which passes the following ratio test $\frac{\Omega_{2nd}}{\Omega_{1st}} \ge \tau$, where Ω_{1st} is a least cost function, Ω_{2nd} is a next least cost function, and τ is a threshold;

(12) providing a plurality of baseline vectors in the WGS-84 frame by

obtaining the relative positions of remaining antennas to the reference antenna from the carrier phase measurement using the ambiguity integer which passed the ratio test;

(13) defining the position of the reference antenna as the origin of the vehicle body frame and transforming the multiple baseline vectors of the WGS-84 frame to vectors of the navigation frame using the prepared coefficients.

18. The method of claim 17, wherein the value b is substituted by a value b' which is increased by a predetermined value b_{ε} to avoid the result that the upper and lower bounds of the search range become imaginary values in case that g1 and g2 values inside the square root of the (7)th step become negative due to the measurement error of baseline length.

19. The method of claim 17, wherein the method of arranging the order of the satellite in the (6)th step comprises the steps of:

(6-1) choosing four satellites in the order of elevation angles for more than five satellites;

(6-2) deciding whether the PDOP value calculated from the four satellites exceeds 6; and

(6-3) in case that the PDOP value does not exceed 6, arranging the four satellites in the order of elevation angles.

20. The method of claim 17, wherein the method of arranging the order of the satellite in the (6)th step comprises the steps of:

(6-1) choosing four satellites in the order of elevation angles for more than five satellites;

(6-2) deciding whether the PDOP value calculated from the four satellites exceeds 6; and

(6-3) in case that the PDOP value exceeds 6, choosing one more satellite having the next largest elevation angle, and then extracting four satellites to make

PDOP value less than 6; and

(6-4) arranging the extracted four satellites in the order of elevation angles.

21. The method of claim 17, wherein the ratio test of the (11)th step begins when the number of the ambiguity integer candidates remained after all the ambiguity integers are searched is less than 10% of the total candidates.

22. The method of claim 21, wherein the threshold of the ratio test is in the range of 1.5 to 7.

23. A method for determining the attitude of a vehicle using GPS carrier phase transmitted by a plurality of satellites, the method comprising the steps of:

(1) providing known baseline length(s) for at least two antennas including a reference antenna which are mounted on the vehicle and preparing coefficients for coordinate transformation between the WGS-84 frame and the navigation frame;

(2) receiving GPS code and phase signals by the antennas at an epoch in order to obtain pseudoranges by processing the received signals using time-synchronized receiver channels, and then transferring the pseudoranges to a microcomputer unit;

(3) deciding at every epoch whether the number of satellites is more than four;

(4) in case that the number of satellites is more than four, determining the position of a reference antenna using GPS code measurements of the satellites at the microcomputer unit;

(5) in case that ambiguity integers of the GPS carrier phase signals are not determined, deciding whether any known one of the ambiguity integers can be used;

(6) in case that any known ambiguity integer can be used, arranging two

satellites related to the known ambiguity integer in the order of elevation angles, adding more than three observed remaining satellites, and then arranging the satellites on the basis of the PDOP values of their respective arrangement;

(7) determining the search range of independent ambiguity integer n_2 and n_3 as follows by using the covariance estimated from the double-differenced code and carrier phase equations including only independent ambiguity integer term as well as the constraint that the baseline lengths are invariant;

known ambiguity integer n_1 is fixed, and

$$\max(\widehat{n_2}-\delta n_2, \frac{-\sqrt{g_1}}{\lambda x_{22}}+\xi_1)\le n_2\le \min(\widehat{n_2}+\delta n_2, \frac{\sqrt{g_1}}{\lambda x_{22}}+\xi_1)$$

$$n_3=\frac{\pm\sqrt{g_2}}{\lambda x_{33}}+\xi_2$$

(8) preparing the calculated parameters necessary for the search of the independent ambiguity integers;

(9) searching the independent ambiguity integers by the ARCE method within the search range to calculate δN_D, and then accumulating $\delta\Omega(N_I)$ defined from the δN_D only in case that $\delta\Omega(N_I)$ is less than a predetermined threshold, calculating cost function $\Omega(N_I)$ and storing ambiguity integer candidates;

(10) deciding whether the number of the ambiguity integer candidates are more than two;

(11) in case that the number of the ambiguity integer candidates is one, fixing it as a true value and providing a plurality of baseline vectors in the WGS-84 frame by obtaining the relative positions of remaining antennas to the reference antenna from the carrier phase measurement using the determined ambiguity integers;

(12) defining the position of the reference antenna as the origin of the

vehicle body frame and transforming the multiple baseline vectors of the WGS-84 frame to vectors of the navigation frame using the prepared coefficients.

24. The method of claim 23, wherein the value b is substituted by a value b' which is increased by a predetermined value b_{ε} to avoid the result that the upper and lower bounds of the search range become imaginary values in case that g1 and g2 values inside the square root of the (7)th step become negative due to the measurement error of baseline length.

25. The method of claim 23, wherein the method of arranging the order of the satellite in the (6)th step comprises the steps of:

(6-1) choosing remaining satellites in the order of elevation angles;

(6-2) deciding whether the PDOP value calculated from the fixed two satellites and the two satellites selected in the order of elevation angles exceeds 6; and

(6-3) in case that the PDOP value does not exceed 6, arranging the four satellites in the order of elevation angles.

26. The method of claim 23, wherein the method of arranging the order of the satellite in the (6)th step comprises the steps of:

(6-1) choosing remaining satellites in the order of elevation angles;

(6-2) deciding whether the PDOP value calculated from the fixed two satellites and the two satellites selected in the order of elevation angles exceeds 6;

(6-3) in case that the PDOP value exceeds 6, choosing one more satellite having the next largest elevation angle, and then extracting four satellites to make PDOP value less than 6; and

(6-4) arranging the extracted four satellites in the order of elevation angles.

27. A method for determining the attitude of a vehicle using GPS carrier

phase transmitted by a plurality of satellites, the method comprising the steps of:

(1) providing known baseline length(s) for at least two antennas including a reference antenna which are mounted on the vehicle and preparing coefficients for coordinate transformation between the WGS-84 frame and the navigation frame;

(2) receiving GPS code and phase signals by the antennas at an epoch in order to obtain pseudoranges by processing the received signals using time-synchronized receiver channels, and then transferring the pseudoranges to a microcomputer unit;

(3) deciding at every epoch whether the number of satellites is more than four;

(4) in case that the number of satellites is more than four, determining the position of a reference antenna using GPS code measurements of the satellites at the microcomputer unit;

(5) in case that ambiguity integers of the GPS carrier phase signals are not determined, deciding whether any known one of the ambiguity integers can be used;

(6) in case that any known ambiguity integer can be used, arranging two satellites related to the known ambiguity integer in the order of elevation angles, adding more than three observed remaining satellites, and then arranging the satellites on the basis of the PDOP values of their respective arrangement;

(7) determining the search range of independent ambiguity integer n_2 and n_3 as follows by using the covariance estimated from the double-differenced code and carrier phase equations including only independent ambiguity integer term as well as the constraint that the baseline lengths are invariant;

known ambiguity integer n_1 is fixed, and

$$\max(\widehat{n_2}-\delta n_2, \frac{-\sqrt{g_1}}{\lambda x_{22}}+\xi_1)\leq n_2\leq \min(\widehat{n_2}+\delta n_2, \frac{\sqrt{g_1}}{\lambda x_{22}}+\xi_1)$$

$$n_3=\frac{\pm\sqrt{g_2}}{\lambda x_{33}}+\xi_2$$

(8) preparing the calculated parameters necessary for the search of the independent ambiguity integers;

(9) searching the independent ambiguity integers by the ARCE method within the search range to calculate δN_D, and then accumulating $\delta\,\Omega(N_I)$ defined from the δN_D only in case that $\delta\,\Omega(N_I)$ is less than a predetermined threshold, calculating cost function $\Omega(N_I)$ and storing ambiguity integer candidates;

(10) deciding whether the number of the ambiguity integer candidates are more than two;

(11) in case that the number of the ambiguity integer candidates is more than two, fixing one as a true value which passes the following ratio test $\frac{\Omega_{2nd}}{\Omega_{1st}}\geq\tau$, where Ω_{1st} is a least cost function, Ω_{2nd} is a next least cost function, and τ is a threshold;

(12) providing a plurality of baseline vectors in the WGS-84 frame by obtaining the relative positions of remaining antennas to the reference antenna from the carrier phase measurement using the ambiguity integer which passed the ratio test;

(13) defining the position of the reference antenna as the origin of the vehicle body frame and transforming the multiple baseline vectors of the WGS-84 frame to vectors of the navigation frame using the prepared coefficients.

28. The method of claim 27, wherein the value b is substituted by a value b' which is increased by a predetermined value b_ε to avoid the result that the upper and lower bounds of the search range become imaginary values in case